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MCDONNELL DOUGLAS TECHNICAL SERVICES CO.
HOUSTON ASTRONAUTICS DIVISION

SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT

DESIGN NOTE NO. 1.4-7-53

ALT SEPARATION REFERENCE TRAJECTORIES FOR TAILCONE ON ORBITER FORWARD AND AFT CG CONFIGURATIONS

MISSION PLANNING, MISSION ANALYSIS AND SOFTWARE FORMULATION

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GLOSSARY

ALT	APPROACH AND LANDING TEST
cg	CENTER OF GRAVITY
FRL	FUSELAGE REFERENCE LINE
JSC	JOHNSON SPACE CENTER
KCAS	KNOTS CALIBRATED AIRSPEED
KEAS	KNOTS EQUIVALENT AIRSPEED
L_B	VEHICLE BODY LENGTH
MDTSCO	MCDONNELL DOUGLAS TECHNICAL SERVICES COMPANY
MPAD	MISSION PLANNING AND ANALYSIS DIVISION
MSL	MEAN SEA LEVEL

1.0 SUMMARY

This report documents a preflight analysis of the ALT separation reference trajectories for the tailcone on, forward and aft cg orbiter configurations. The ALT separation reference trajectories encompass the time from physical separation of the orbiter from the carrier to orbiter attainment of the maximum ALT interface airspeed. The trajectories include post separation roll maneuvers by both vehicles and are generated using the final preflight data base. The trajectories so generated satisfy all known separation design criteria and violate no known constraints.

The requirement for this analysis is elaborated upon in Section 2.0. The specifications, assumptions and analytical approach used to generate the separation trajectories are presented in Section 3.0. The results of the analytical approach are evaluated in Section 4.0. Conclusions and recommendations are summarized in Section 5.0. Supporting references are listed in Section 6.0.

2.0 INTRODUCTION

ALT separation reference trajectories of the carrier and orbiter are required to support the JSC MPAD updates to the reference trajectories for ALT free flights #1 through #5 which supercede Reference 1. The ALT separation reference trajectories encompass the flight time duration between physical separation of the orbiter from the carrier and orbiter attainment of the maximum ALT interface airspeed. This analysis updates that of Reference 1 in that post separation roll maneuvers are executed by both vehicles instead of just the carrier and that the final preflight data base is used. Toward that end this MDTSCO "ALT Separation Reference Trajectories for Tailcone On Orbiter Forward and Aft CG Configurations" is generated.

3.0 DISCUSSION

This section summarizes the specifications, assumptions, and analytical approach used in this analysis. Maximum utilization of previous analyses is made in order to expedite definition of the ALT separation reference trajectories. Source data is referenced accordingly in the subsequent text.

In this analysis, the ALT orbiter/carrier separation is simulated by the Space Vehicle Dynamics Simulation (SVDS) Program (see Reference 2) in two flight phases. The separation flight phase is initiated at the instant of orbiter release and is defined to be 5 sec in duration. The post separation flight phase begins 5 sec after separation and is terminated by the orbiter attainment of the maximum ALT interface airspeed.

3.1 Specifications

The specifications for the ALT separation reference trajectories follow. Unless otherwise noted, the specifications are from Reference 3.

1) Orbiter/carrier (mated) separation initial conditions design criteria and constraints:
   a) The relative normal acceleration (normal to the carrier FRL) must be no less than 0.75 g's.
   b) The orbiter pitch acceleration must be in the range of 0 to 6 deg/sec^2.

c) The orbiter normal load factor must be in the range of 0 to 2 g's.

d) The carrier normal load factor must be in the range of -1 to 2 g's.

e) The separation airspeed must be less than an airspeed of 292 KCAS; or a Mach number of 0.675, or the airspeed obtained from the mated configuration V-N diagram presented in Reference 4 and attendant rationale (5 KCAS less than the 1.1 g airspeed on the 75% mated configuration V-N diagrams).

2) Orbiter/carrier separation flight phase design criteria and constraints:

a) The relative normal acceleration must be maintained positive until the orbiter is clear of the carrier.

b) Vertical separation clearance distance between the cg's of the respective vehicles (as measured in the carrier reference coordinate system) must exceed 140 ft.

c) The separation cone angle (the angle of the orbiter trajectory relative to the carrier vertical axis) must be no greater than 20 deg until the 140 ft vertical separation clearance distance is attained.

d) The orbiter normal load factor must be in the range of 0 to 2 g's for airspeeds no greater than 285 KEAS.

e) The orbiter angle of attack must be in the range of 3 to 13 deg.

f) The carrier normal load factor must be in the range of -1 to 2.25 g's.

g) The carrier airspeed must be maintained below the 312 KCAS and the 0.7 Mach number design limits.

3) Orbiter/carrier post separation flight phase design criteria and constraints:

a) The minimum path distance (between the current orbiter cg position and the flight path of the carrier cg) must exceed 140 ft when the time rate of change of minimum path distance remains positive (vortex avoidance).

b) The orbiter constraints are the same as those for the separation flight phase with the exception that the normal load factor must be greater than 0.5 g's (Reference 5).

c) The orbiter local horizontal pitch attitude must be no steeper than -10 deg (crew preference, Reference 5).

d) The carrier constraints are the same as those for the separation flight phase.

3.2 Assumptions

Three categories of assumptions are used for this analysis. Category one entails the data base assumptions. Category two consists of the flight sequence assumptions. Category three

contains assumptions pertinent to the analytical approach.

The data base assumptions follow.

1) Orbiter configuration:
   a) Tailcone on.
   b) Forward and aft cg locations.
   c) Body flap at -11.7 deg.
   d) Control system as defined in Reference 6.

2) Carrier configuration:
   a) Landing flaps retracted.
   b) Landing gear up.
   c) Inflight spoiler deployed.
   d) Thrust at idle.
   e) Thrust magnitude as defined in Reference 7.
   f) Control system as defined in Reference 8.

3) Separation altitudes as defined in Reference 9.

4) Freestream and proximity aerodynamics data for both vehicles as defined in Reference 10.

5) Mass characteristics as defined in Reference 11.

The flight phase sequence assumptions are divided into two subcategories. The first subcategory is the separation flight phase

sequence assumptions. The second subcategory is the post separation flight phase sequence assumptions.

The separation flight phase sequence assumptions follow.

1) The separation flight phase is defined to be 5 sec in duration.

2) The orbiter control system is in the CAS (rate command) mode during which time the orbiter pitch rate command is a constant 2 deg/sec for the first 3 sec and 0 deg/sec for the remaining 2 sec.

3) The carrier maintains the mated vehicle equilibrium glide pitch attitude command for the duration of the separation flight phase.

The post separation flight phase sequence assumptions follow.

1) The time duration of the post separation flight phase is determined by the orbiter attainment of the maximum ALT interface airspeed (300 KEAS).

2) The orbiter control system remains in the CAS mode, during which time the orbiter performs a commanded -1 deg/sec pitch-over maneuver in order to attain the maximum ALT interface airspeed. (The orbiter local horizontal pitch attitude is limited to -10 deg.)

3) The orbiter is also commanded to bank to the right at its maximum roll rate command until a local horizontal roll attitude of 20 deg is attained. The roll attitude of 20 deg is held until a heading change of approximately 3 deg is made at which time the orbiter is commanded to roll back to wings level at its maximum roll rate command.

4) The carrier local horizontal pitch attitude command is pitched up an incremental 2 deg at a 2 deg/sec rate in order to moderate carrier post separation airspeed buildup.

5) The carrier is commanded to bank to the left at a 10 deg/sec rate until a local horizontal roll attitude command of -30 deg is attained. The -30 deg roll attitude is held until a heading of approximately -30 deg is attained at which time the carrier is commanded to roll back to wings level.

Assumptions which simplify the analytical approach follow.

1) Only nominal conditions are assumed. No system nor environmental tolerances are analyzed.

2) The forward and aft cg configurations for the light weight, tailcone on orbiter (ALT Free Flights #1 through #5) are analyzed.

3) Only the second launch opportunity mass characteristics (the

same mass characteristics used for a single launch opportunity mission) are analyzed.

3.3 Analytical Approach

The overall analytical approach consists of generating an orbiter/carrier ALT separation reference trajectory for each of the two orbiter cg configurations. Toward that end, a three step analytical approach common to both trajectories is used.

The first step is to generate the separation initial conditions required to produce the RI recommended initial relative normal acceleration and orbiter pitch acceleration (0.753 g's and 2.38 deg/sec^2, respectively for the forward cg orbiter configuration and 0.901 g's and 3.39 deg/sec^2, respectively for the aft cg orbiter configuration, see Reference 3). The Mated Trim Program is used for that purpose (see Reference 12).

The second step is to calibrate the time duration of the carrier -30 deg local horizontal roll attitude command in order that a heading of -30 deg is attained. The SVDS program is used for this purpose.

Combining the results of the first and second steps, the third step generates the ALT separation reference trajectories using the SVDS program.

4.0 RESULTS

This section first presents the results of the analytical approach as outlined in Section 3.3. The ALT separation reference trajectory results are then presented.

The equilibrium glide separation initial conditions required to produce the RI recommended initial relative normal acceleration and orbiter pitch acceleration are presented in Table 1. These results are a product of step one of the analytical approach.

The orbiter and carrier steering summary and the orbiter and carrier separation event schedule are presented in Tables 2 and 3, respectively. These results are a product of steps one and two of the analytical approach.

The results of the orbiter/carrier separation reference trajectory generation are presented in Tables 4 through 6 and Figures 1 through 60. Tables 4 through 6 are design compatibility summaries for the separation initial conditions, the separation flight phase, and the post separation flight phase, respectively. These results show that all design criteria are met and that no constraints are violated. Time histories of parameters of interest are illustrated in Figures 1 through 60.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The ALT separation reference trajectories documented herein satisfy all known separation design criteria and violate no known constraints. These trajectories are generated from the final preflight data base available prior to the ALT captive inert flights. It is therefore recommended that the ALT separation reference trajectories documented herein be used for updates to the reference trajectories for ALT free flights #1 through #5.

6.0 REFERENCES

1) NASA Memorandum FM42 (76-12), "Reference Trajectories for Approach and Landing Test Free Flight Mission 1 with Tailcone," dated 12 March 1976.

2) JSC Internal Note No. 76-FM-26 (JSC-11157), "Space Vehicle Dynamics Simulation (SVDS) Program Description Revision 1," dated 30 November 1976.

3) RI Document No. SD73-SH-0180G, "Space Shuttle Separation System Data Book," dated January 1977.

4) RI Document No. SD76-SH-0151A, "OV-101 Structural Flight Restrictions for Approach and Landing Test Program," dated 4 February 1977.

5) JSC Internal Note No. 76-FM-121 (JSC-11844), "Operational Flight Profiles for Approach and Landing Test (ALT) Orbiter with Tailcone (Free-Flight Missions 1 through 5)," dated 20 January 1977.

6) RI Document No. SD74-SH-0271A, "ALT Level C Functional Subsystem Software Requirements Guidance, Navigation, and Control Part C, Flight Control," dated 13 August 1975.

7) RI Document No. SD75-SH-0033C, Revision 1, "Orbiter/747 Carrier Separation Aerodynamic Data Book," dated November 1976.

8) NASA Memorandum EJ3-74-171, "Definition of 747 FCS and Orbiter FCS for Carrier/Orbiter Simulations at NASA," dated 20 September 1974.

9) TBC Document No. D180-18409-1, "747 Cam/Orbiter Launch Performance," Revision G.

10) MDTSCO TM No. 1.4-4-7-403, "Update of ALT Separation Aerodynamics Data Base," dated 31 March 1977.

11) TBC Document No. D180-18401-13, "747 Space Shuttle Orbiter Carrier Aircraft Modification (CAM) Mass Properties Status Report," dated November 1976.

12) MDTSCO Design Note No. 1.4-7-19, "ALT 747/Orbiter Mated Trim Computer Program," dated 17 November 1975.

13) MDTSCO Design Note No. 1.4-7-49, "Tailcone On Orbiter Altitude Attainable at the Maximum ALT Interface Airspeed," dated 31 March 1976.

TABLE 1

ORBITER/CARRIER EQUILIBRIUM GLIDE SEPARATION INITIAL CONDITIONS
TAILCONE ON; 150000 LB ORBITER

	FORWARD cg (63.9 % L_B)	AFT cg (65.9 % L_B)
RELATIVE NORMAL ACCELERATION (g's)	0.753	0.901
ORBITER PITCH ACCELERATION (deg/sec^2)	2.38	3.39
INCIDENCE ANGLE (deg)	6.0	6.0
ORBITER ELEVON POSITION (deg)	0.045	1.578
MSL ALTITUDE (ft)	24500	24600
AIRSPEED (KEAS)	267.7	265.6
MACH NUMBER (-)	0.657	0.653
FLIGHT PATH ANGLE (deg)	-8.67	-8.58
CARRIER ANGLE OF ATTACK (deg)	2.67	2.66
CARRIER PITCH ATTITUDE (deg)	-6.00	-5.92
CARRIER STABILIZER POSITION (deg)	1.689	1.900
CARRIER ELEVATION POSITION (I/O; deg)	0.0/3.0	0.0/3.0

TABLE 2

ORBITER/CARRIER STEERING SUMMARY

	FORWARD cg (63.9 % L_B)	AFT cg (65.9 % L_B)
ORBITER SEPARATION PITCH RATE COMMAND FIRST 3 SEC/LAST 2 SEC (deg/sec)	2.0/0.0	2.0/0.0
ORBITER POST SEPARATION PITCH RATE COMMAND UNTIL θ = -10 DEG (deg/sec)	-1.0	-1.0
ORBITER POST SEPARATION ROLL RATE/ATTITUDE COMMAND (deg/sec & deg)	18.75/20.0	18.75/20.0
CARRIER SEPARATION PITCH ATTITUDE COMMAND (deg)	-6.00	-5.92
CARRIER POST SEPARATION PITCH ATTITUDE COMMAND (deg)	-4.00	-3.92
CARRIER POST SEPARATION ROLL ATTITUDE COMMAND (deg)	-30.0	-30.0

TABLE 3

ORBITER/CARRIER SEPARATION EVENT SCHEDULE

	FORWARD cg (63.9 % L_B)	AFT cg (65.9 % L_B)
SEPARATE AND INITIATE ORBITER PULLUP MANEUVER	0.0	0.0
INITIATE ORBITER PITCH ATTITUDE HOLD	3.0	3.0
SEPARATION CLEARANCE ATTAINED (140 FT VERTICAL CLEARANCE)	3.4	3.1
START OF POST SEPARATION FLIGHT PHASE INITIATE ORBITER PUSHOVER MANEUVER INITIATE ORBITER ROLL MANEUVER INITIATE CARRIER PULLUP MANEUVER INITIATE CARRIER ROLL MANEUVER	5.0	5.0
CARRIER PULLUP MANEUVER COMPLETED (+2 DEG PITCH ATTITUDE COMMAND COMPLETED)	6.0	6.0
ORBITER ROLL MANEUVER COMPLETED (+3 DEG HEADING CHANGE COMPLETED)	16.0	16.0
ORBITER PUSHOVER MANEUVER COMPLETED (PITCH ATTITUDE HOLD AT -10 DEG)	22.0	22.0
CARRIER ROLL MANEUVER COMPLETED (-30 DEG HEADING ATTAINED)	36.0	36.0
MAXIMUM ALT INTERFACE AIRSPEED ATTAINED (300 KEAS ATTAINED)	43.0	47.0

TABLE 4

ORBITER/CARRIER SEPARATION INITIAL CONDITIONS DESIGN COMPATIBILITY SUMMARY

	FORWARD cg (63.9 % L_B)	AFT cg (65.9 % L_B)
RELATIVE NORMAL ACCELERATION ($\geq$ 0.75 g's)	0.753	0.901
ORBITER PITCH ACCELERATION ($\geq$ 0 & $\leq$ 6 deg/sec^2)	2.38	3.39
ORBITER NORMAL LOAD FACTOR ($\geq$ 0 & $\leq$ 2 g's)	1.532	1.640
CARRIER NORMAL LOAD FACTOR ($\geq$ -1 & $\leq$ 2 g's)	0.773	0.732
SEPARATION AIRSPEED (FWD cg, 268 KEAS & AFT cg, 266 KEAS)*	267.7	265.6

*SEE REFERENCE 13

TABLE 5

ORBITER/CARRIER SEPARATION FLIGHT PHASE DESIGN COMPATIBILITY SUMMARY

	FORWARD cg (63.9 % L_B)	AFT cg (65.9 % L_B)
MINIMUM RELATIVE NORMAL ACCELERATION (≥ 0 g's UNTIL VERTICAL CLEARANCE IS ≥ 140 ft)	0.60	0.69
VERTICAL CLEARANCE AT THE END OF THE SEPARATION FLIGHT PHASE (≥ 140 ft)	269.3	311.6
SEPARATION CONE ANGLE WHEN VERTICAL CLEARANCE = 140 ft (≤ 20 deg)	7.23	8.08
ORBITER LOAD FACTOR RANGE (≥ 0 & ≤ 2 g's)	1.14-1.82	1.10-1.86
ORBITER ANGLE OF ATTACK RANGE (≥ 3 & ≤ 13 deg)	6.3-8.85	5.66-8.66
CARRIER LOAD FACTOR RANGE (≥ -1 & ≤ 2.25 g's)	0.773-1.01	0.732-0.99
MAXIMUM CARRIER AIRSPEED/MACH NUMBER (≤ 312 KCAS/0.7)	276/0.657	274/0.653

TABLE 6

ORBITER/CARRIER POST SEPARATION FLIGHT PHASE DESIGN COMPATIBILITY SUMMARY

	FORWARD cg (63.9 % L_B)	AFT cg (65.9 % L_B)
MINIMUM PATH DISTANCE AT THE START OF THE POST SEPARATION FLIGHT PHASE ($\geq$ 140 ft WHEN MPD REMAINS > 0)	269.6	309.5
ORBITER LOAD FACTOR RANGE ($\geq$ 0.5 & $\leq$ 2 g's)	0.64-1.153	0.645-1.118
ORBITER ANGLE OF ATTACK RANGE ($\geq$ 3 & $\leq$ 13 deg)	3.78-5.00	3.58-4.73
MINIMUM ORBITER PITCH ATTITUDE ($\geq$ -10 deg)	-10.0	-10.0
CARRIER LOAD FACTOR RANGE ($\geq$ -1 & $\leq$ 2.25 g's)	0.982-1.42	0.983-1.40
MAXIMUM CARRIER AIRSPEED/MACH NUMBER ($\leq$ 312 KCAS/0.7)	276/0.651	274/0.648

FIGURE 1

ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

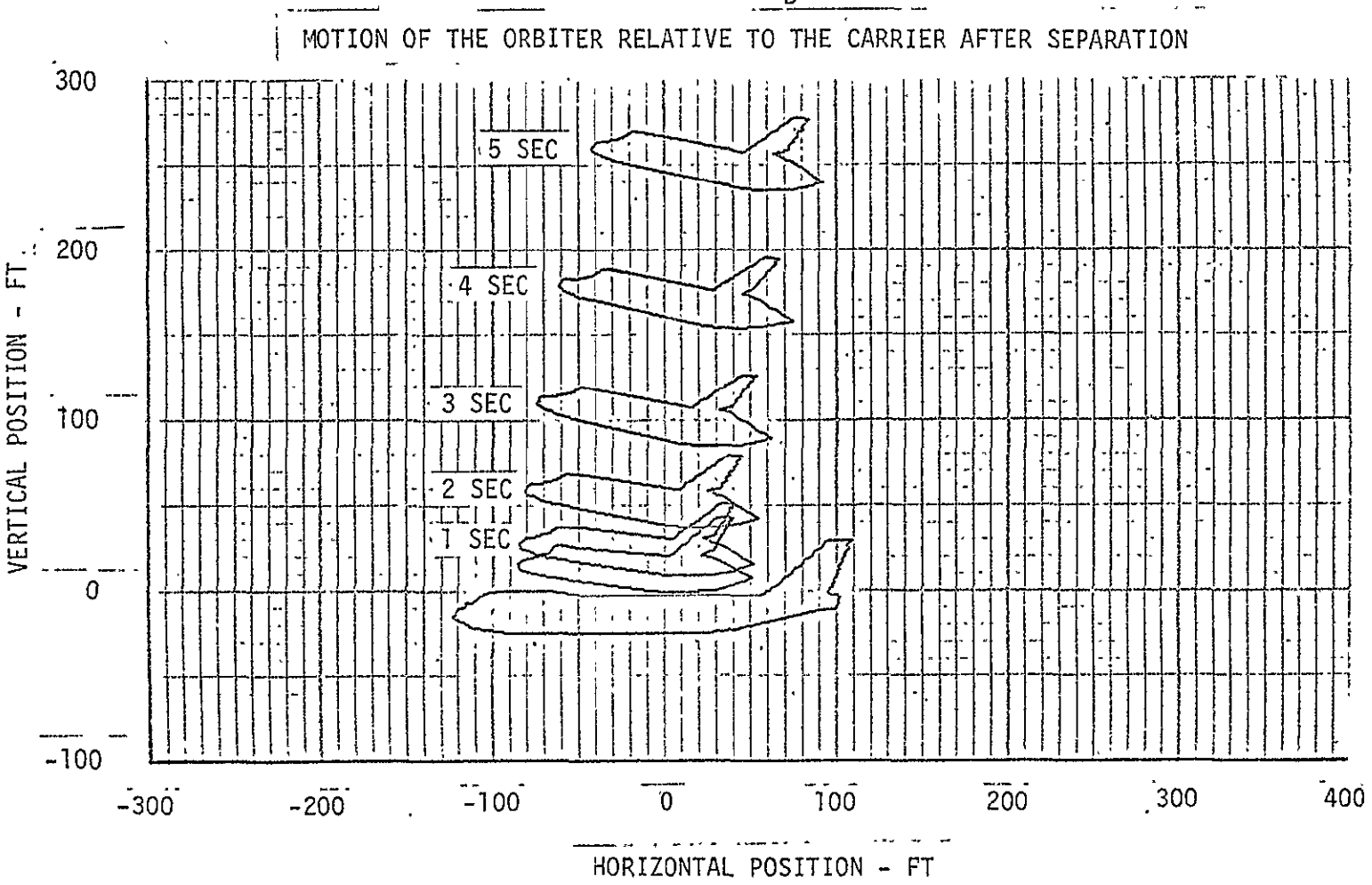

FIGURE 2
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

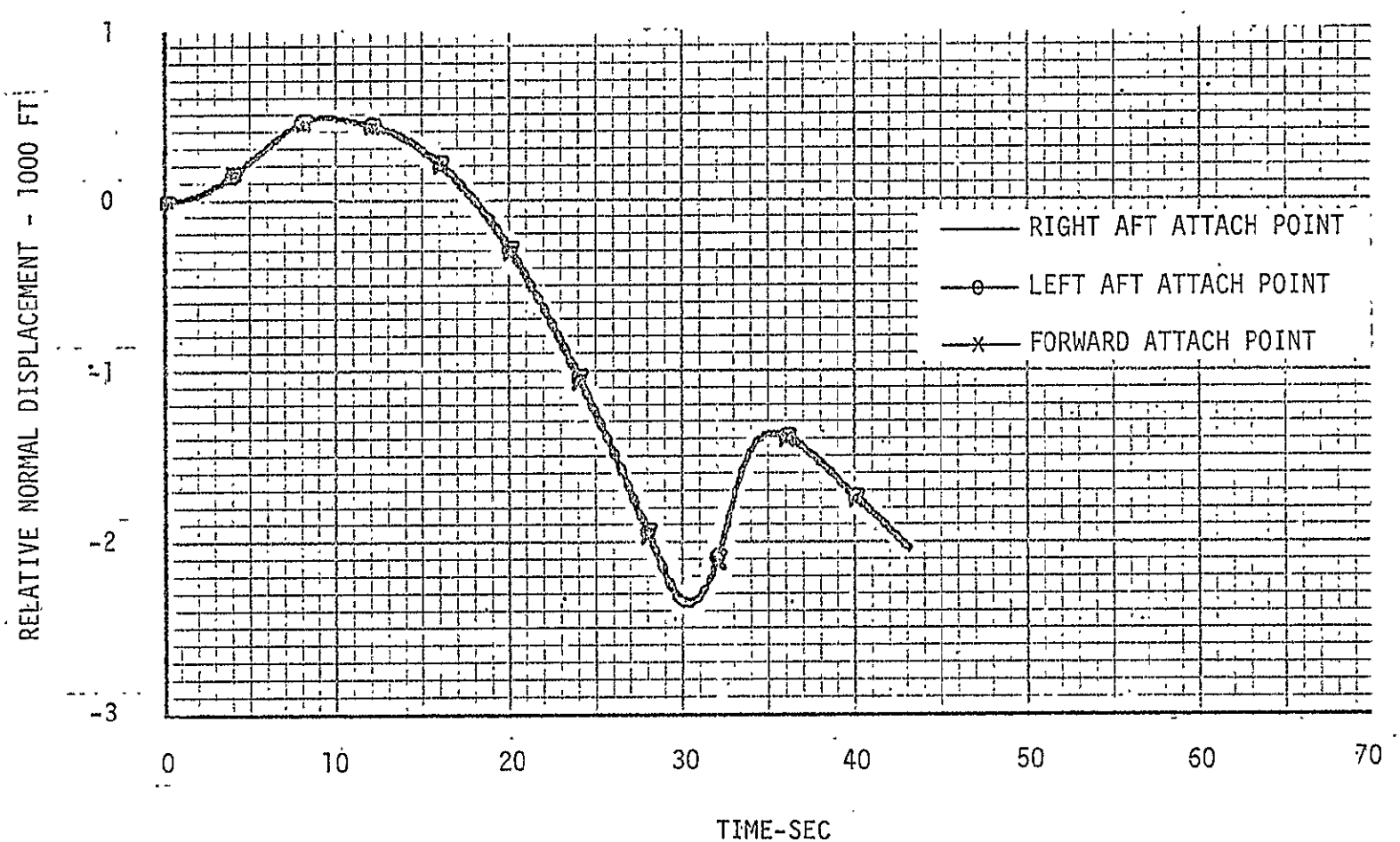

FIGURE 3
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

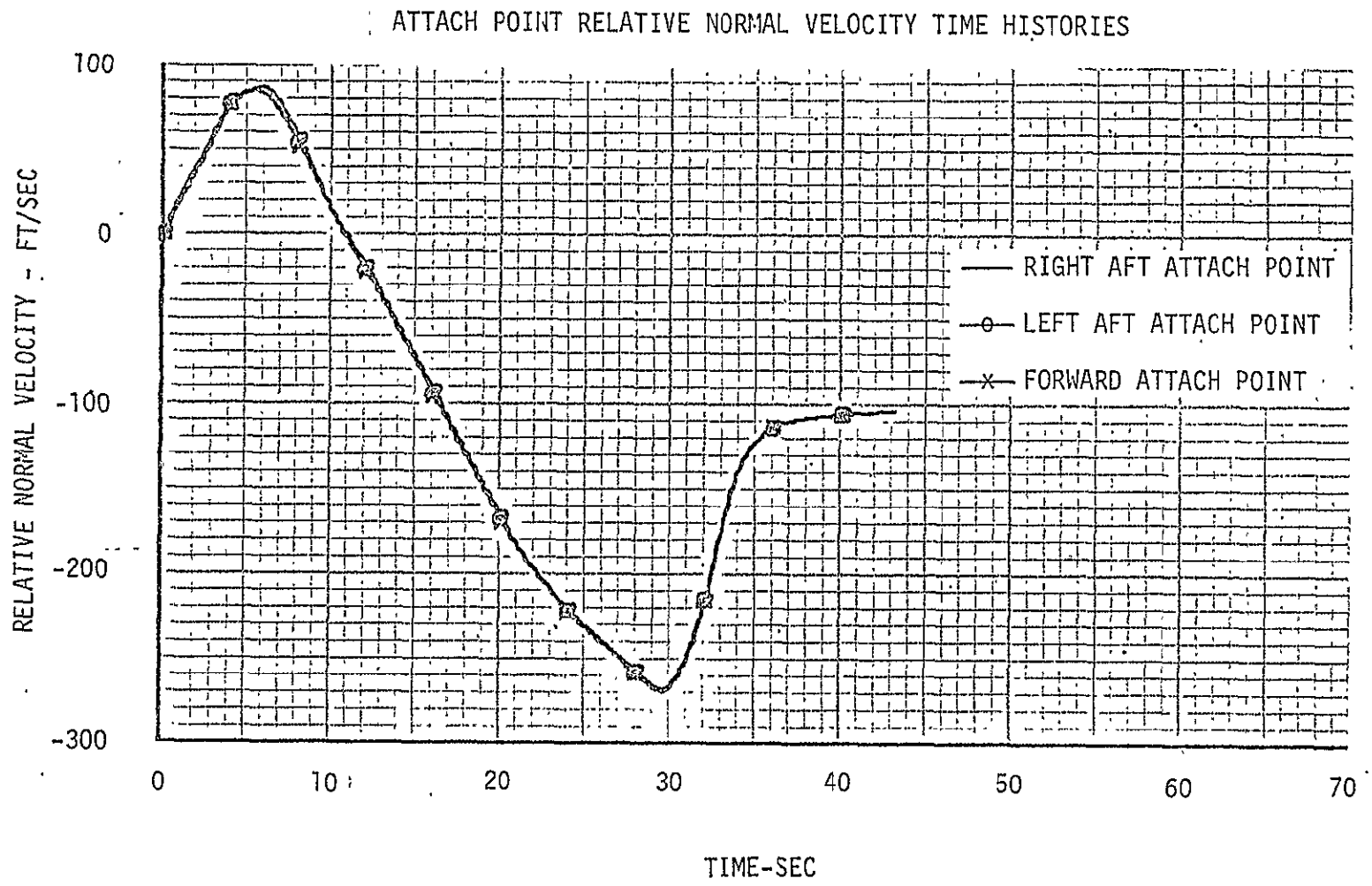

FIGURE 4
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

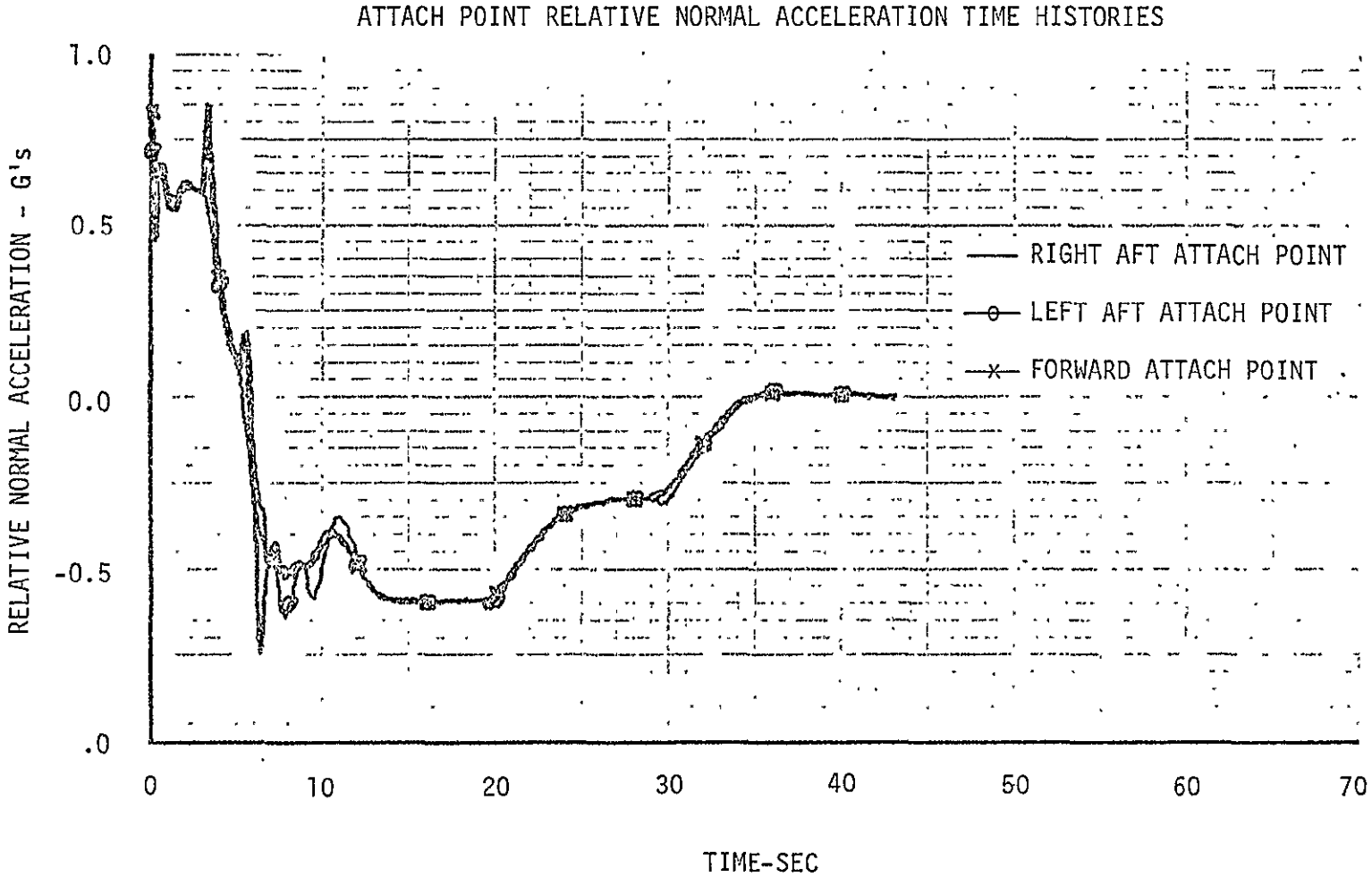

FIGURE 5
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

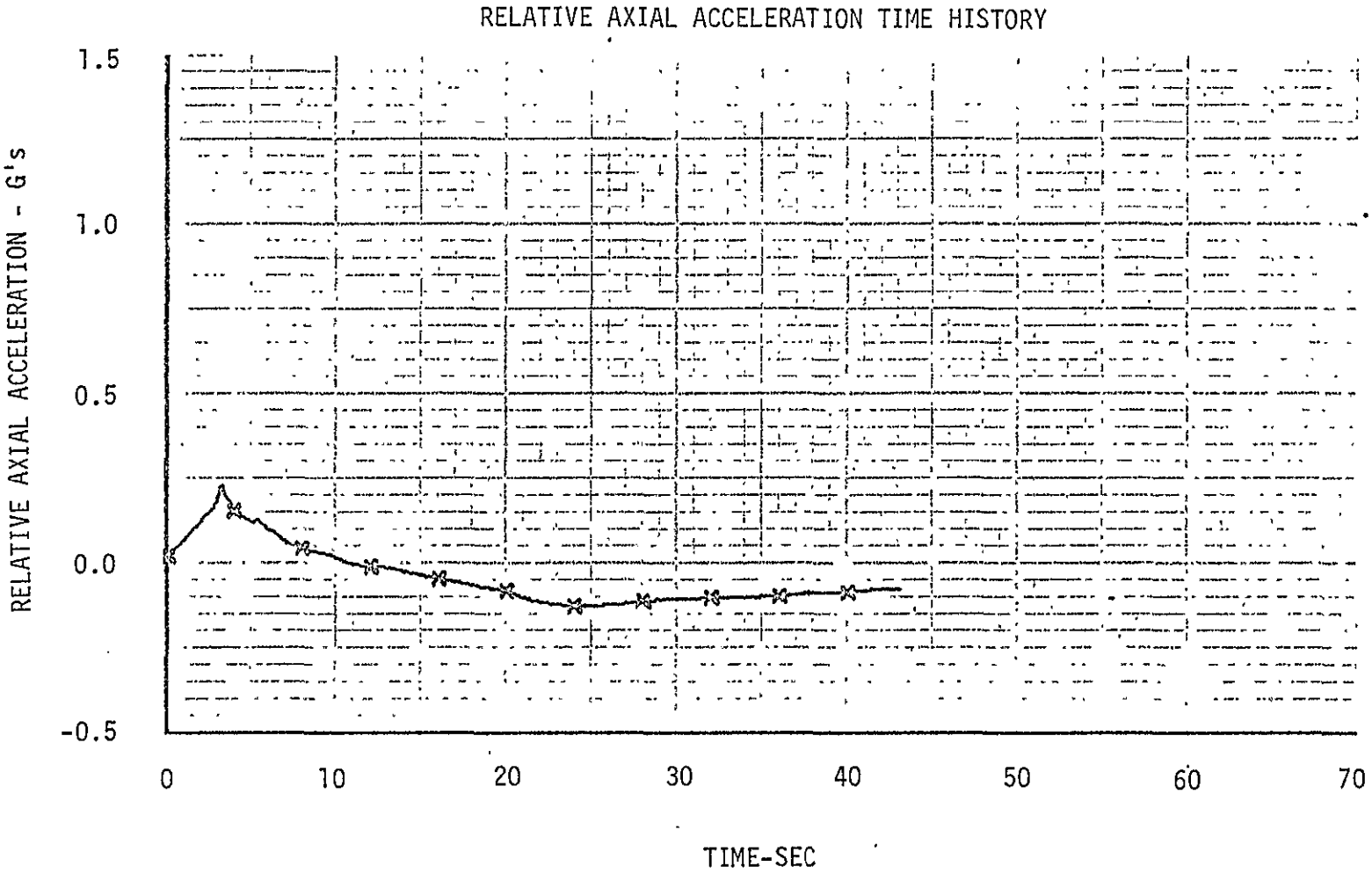

FIGURE 6
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

RELATIVE NORMAL ACCELERATION TIME HISTORY

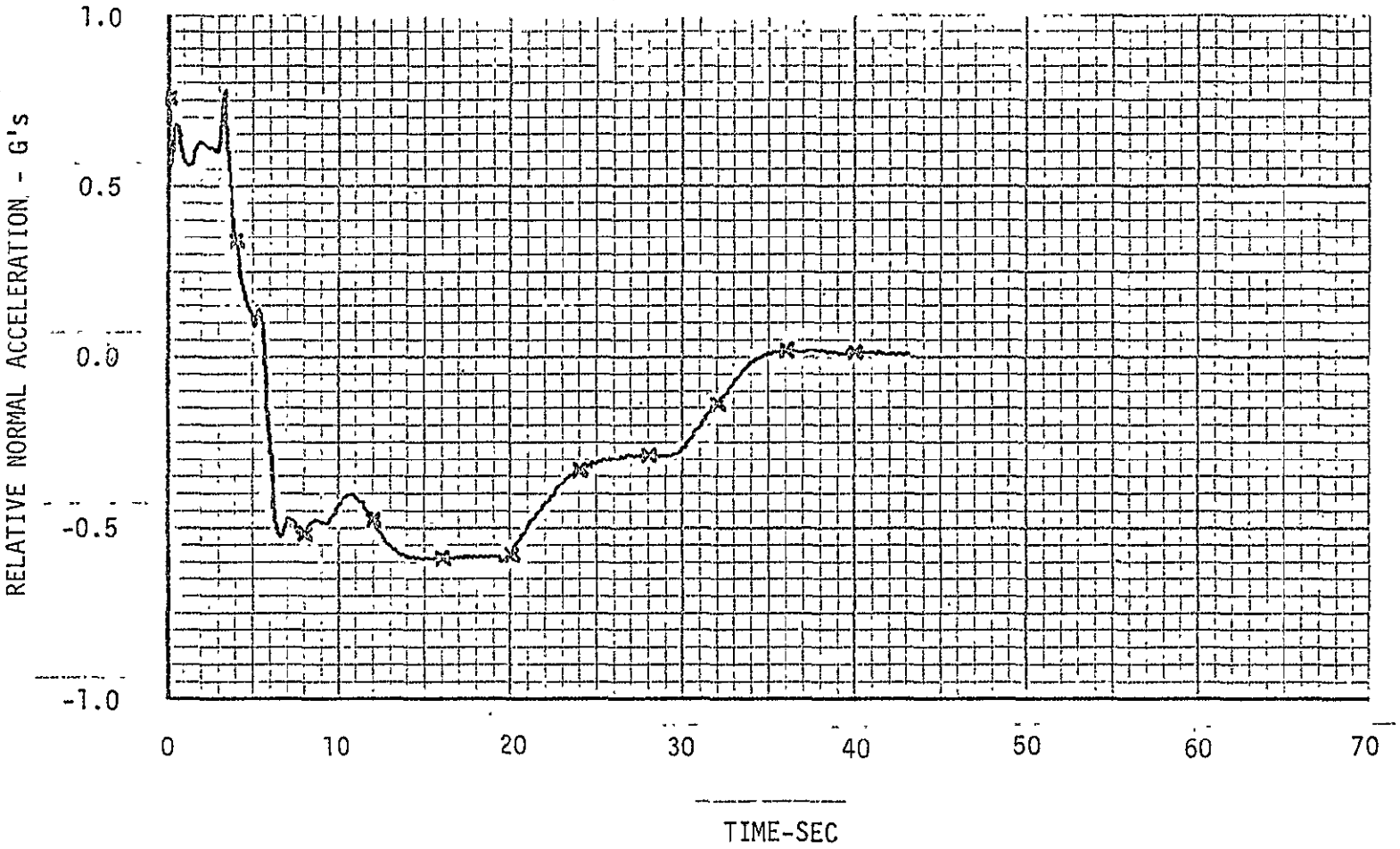

FIGURE 7
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

RELATIVE DOWNRANGE VERSUS RELATIVE CROSSRANGE

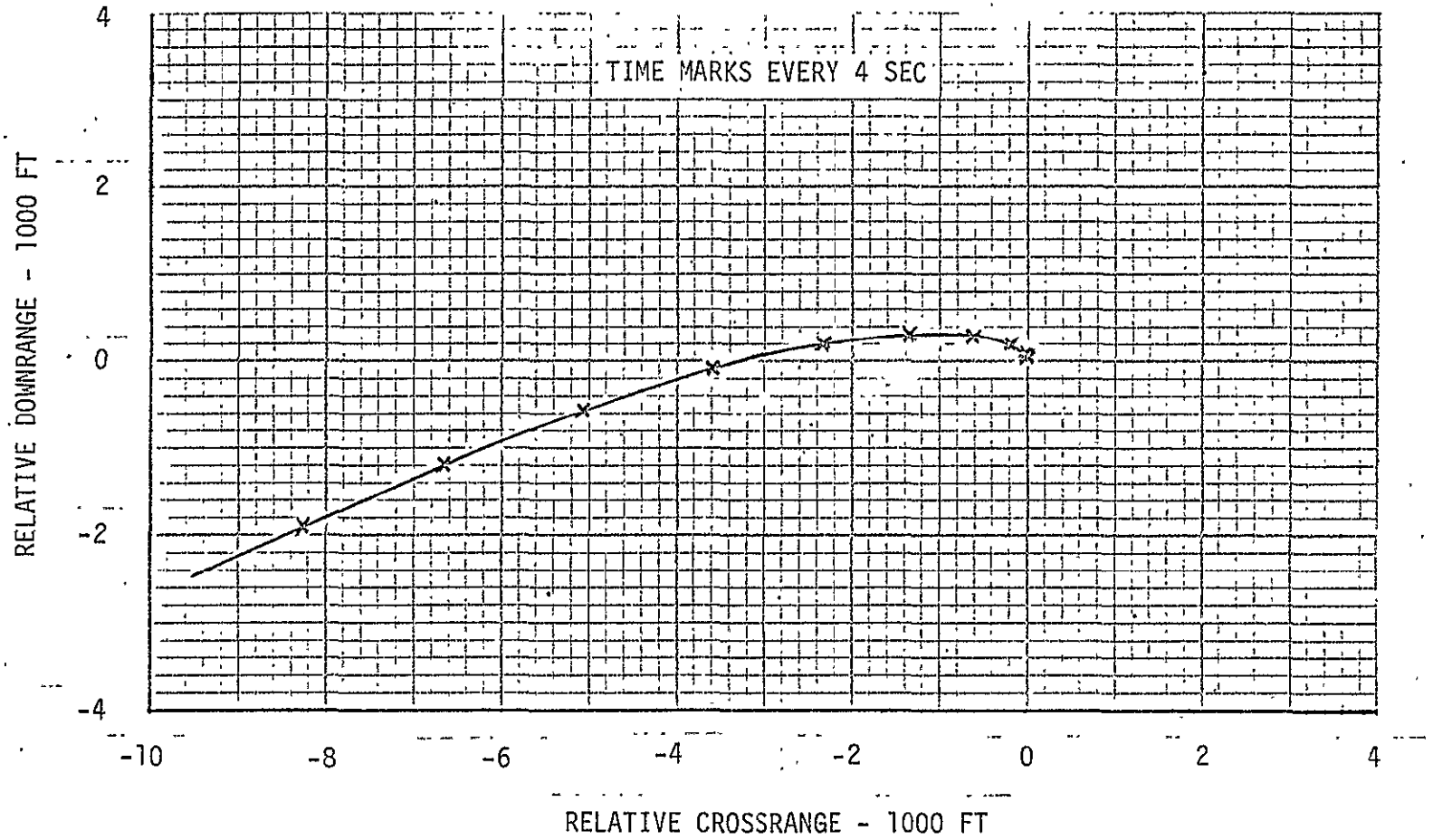

FIGURE 8
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

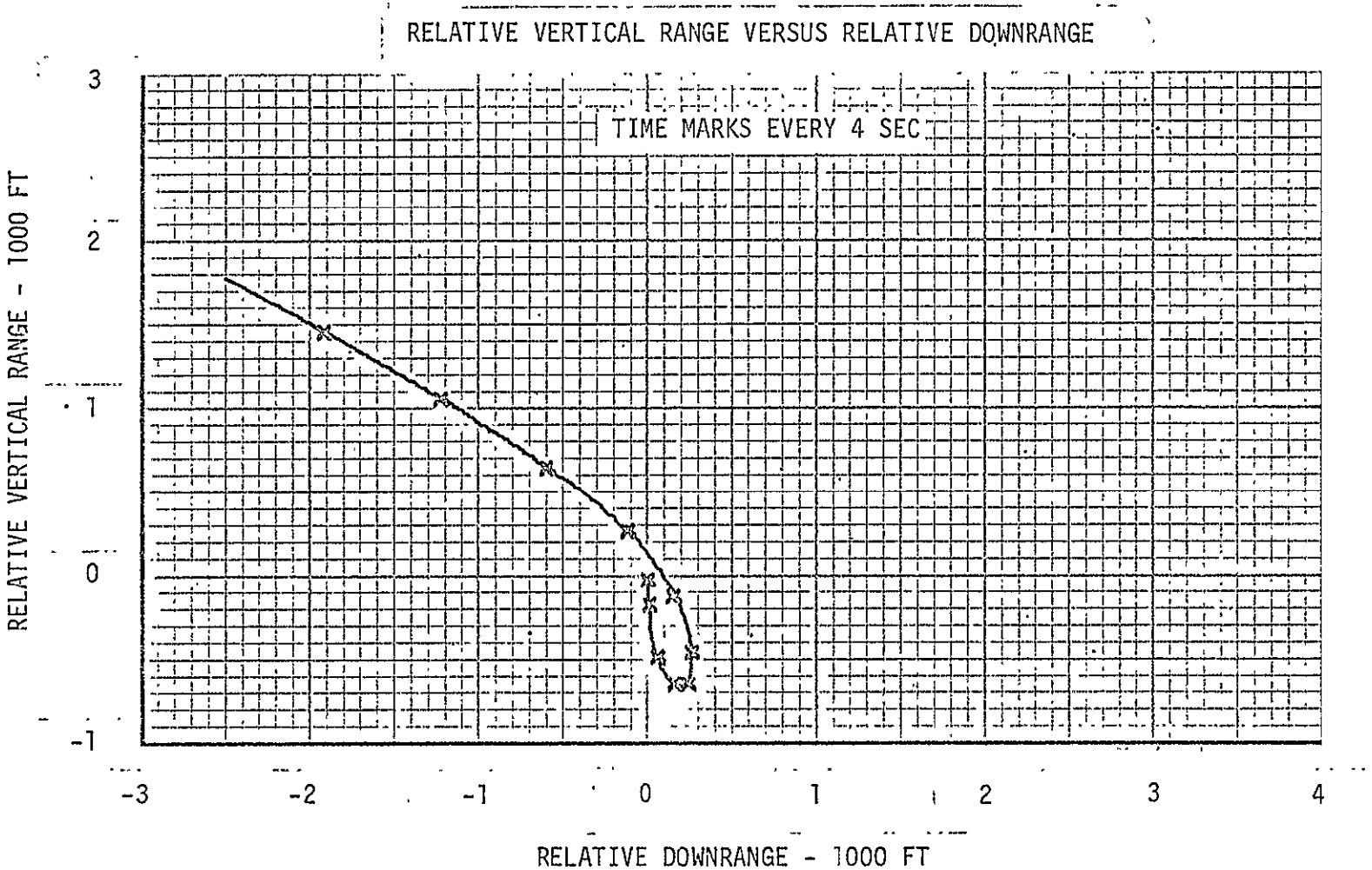

FIGURE 9
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

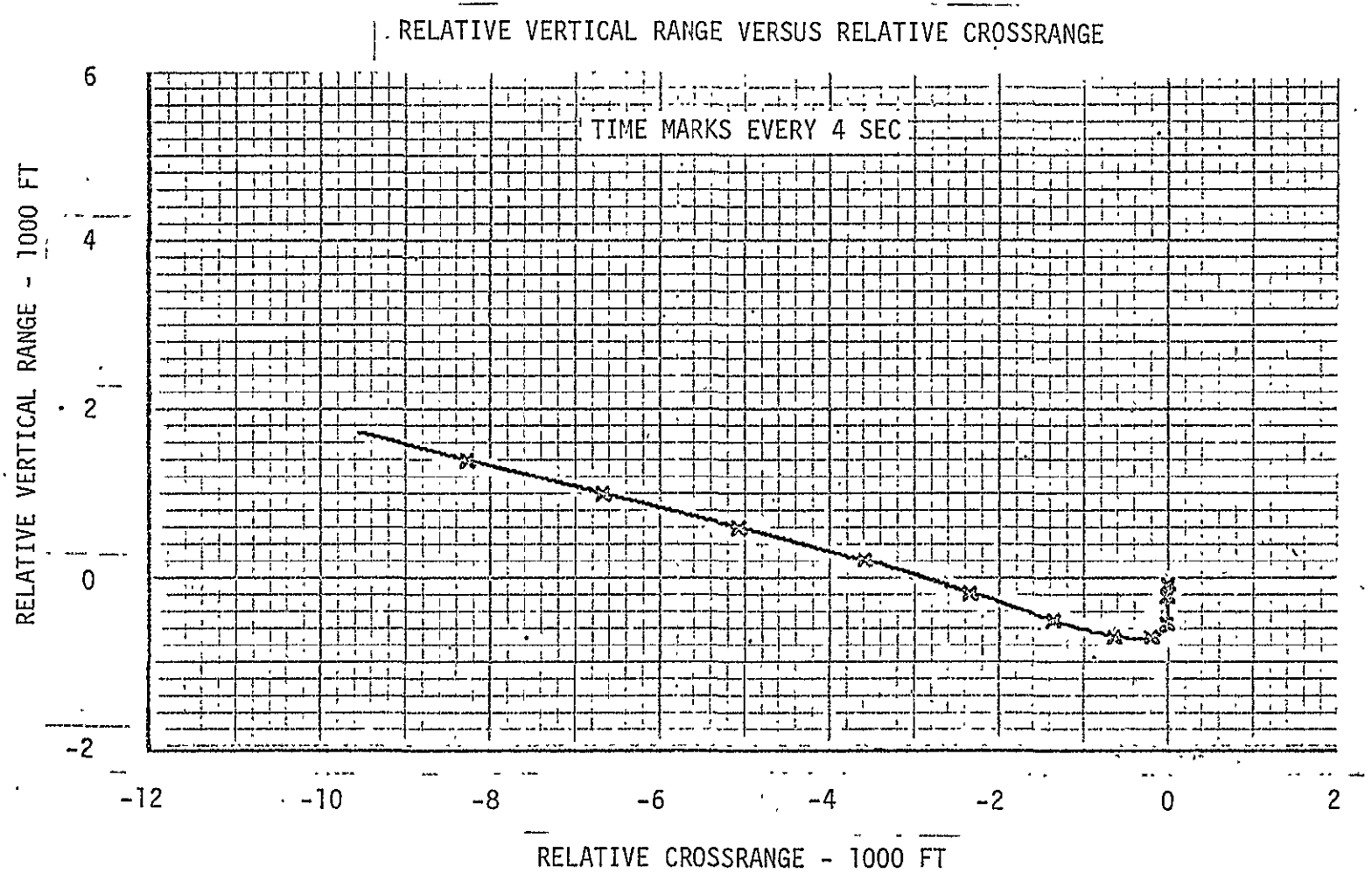

FIGURE 10
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

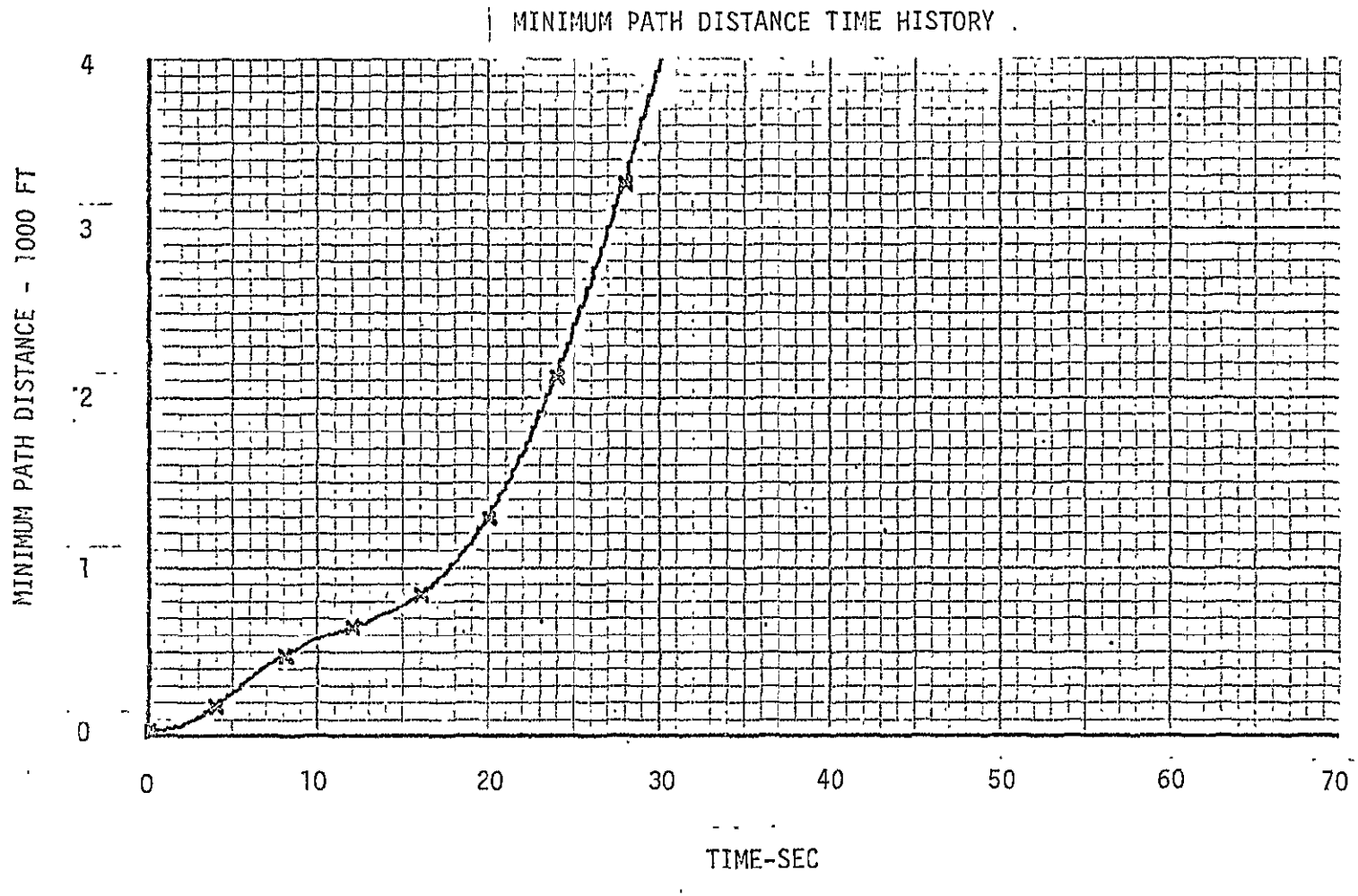

FIGURE 11
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

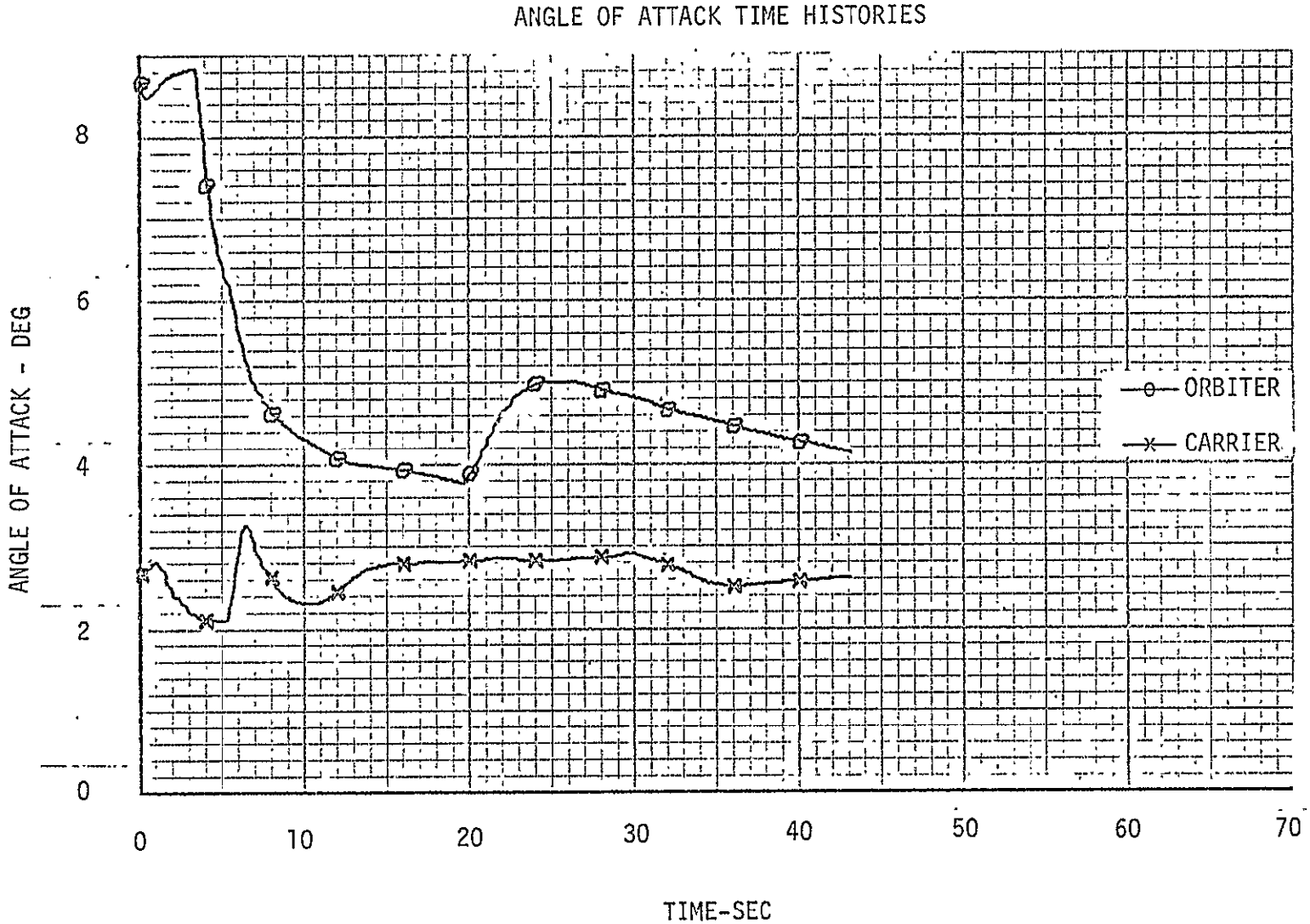

FIGURE 12
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

SIDESLIP ANGLE TIME HISTORIES

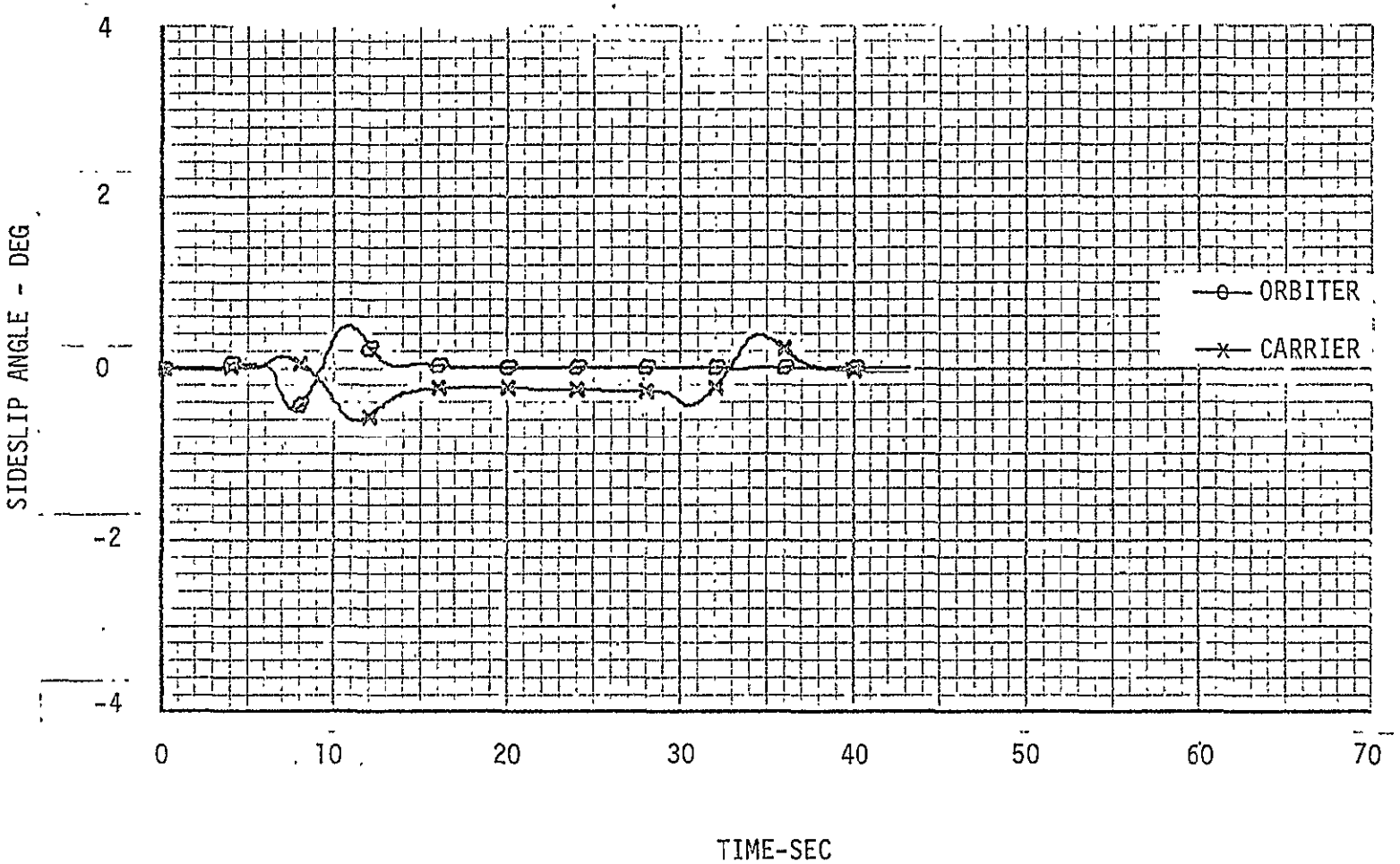

FIGURE 13
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

FLIGHT PATH ANGLE TIME HISTORIES

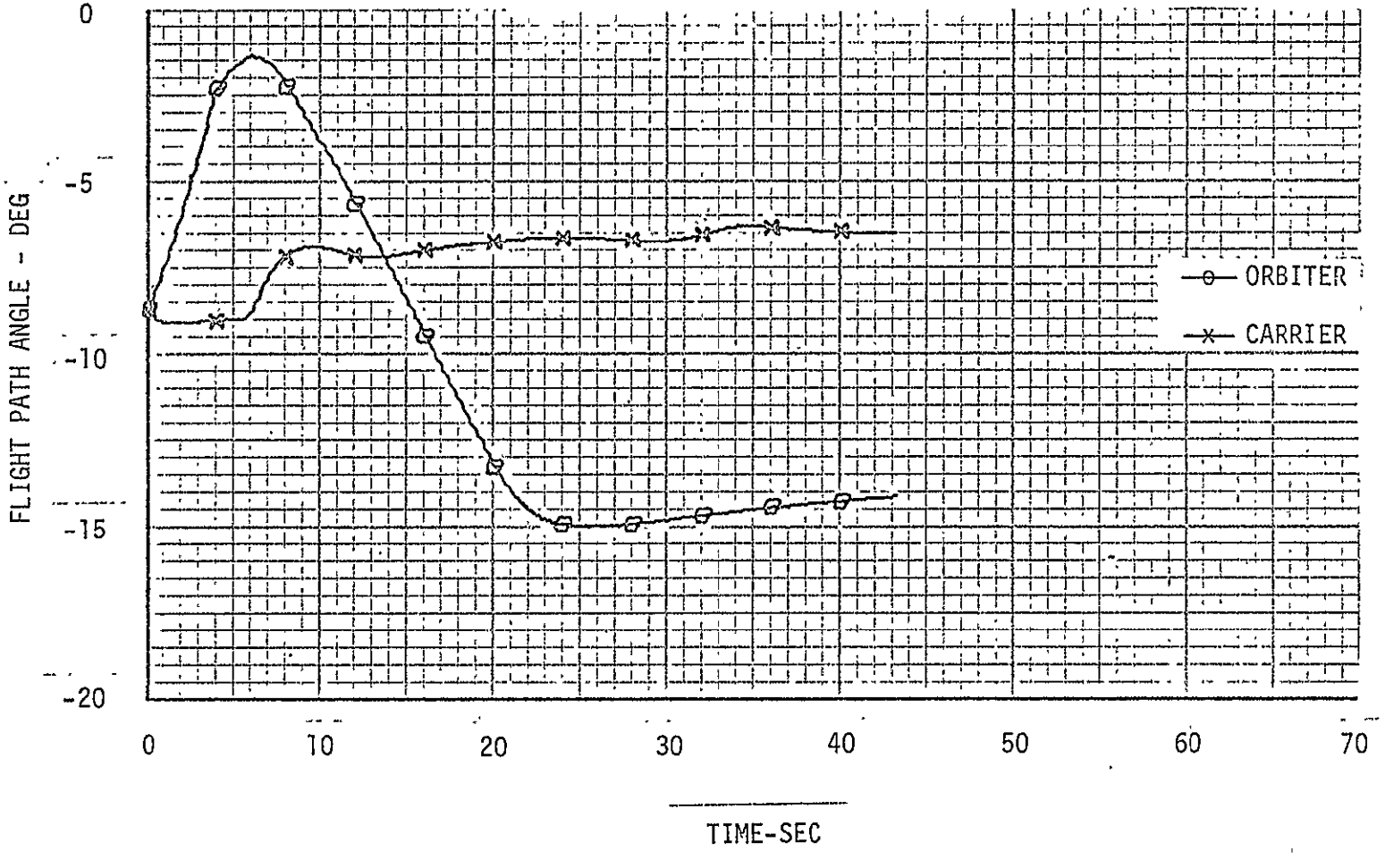

FIGURE 14
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

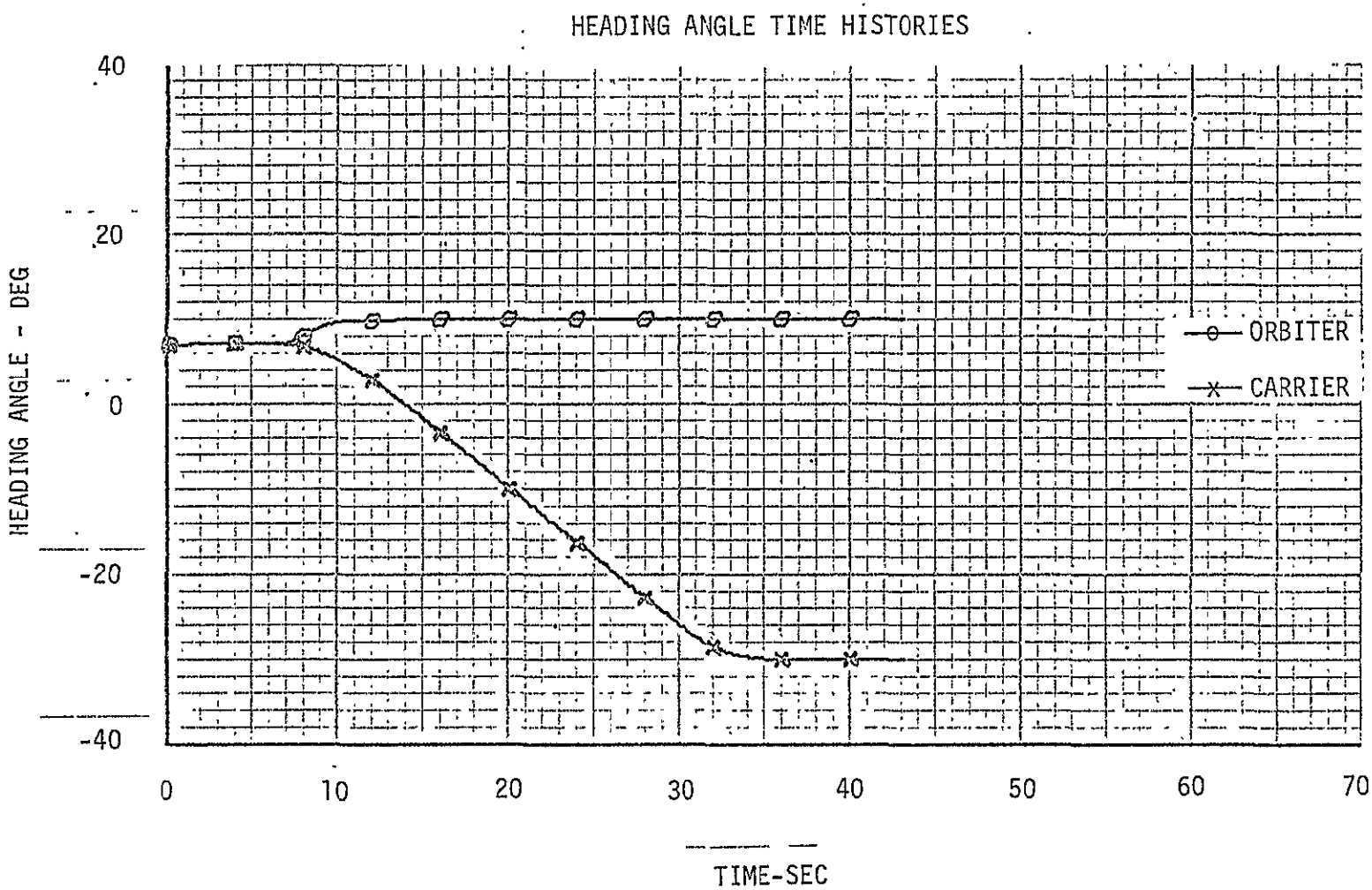

FIGURE 15
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

LOCAL HORIZONTAL PITCH ATTITUDE TIME HISTORIES

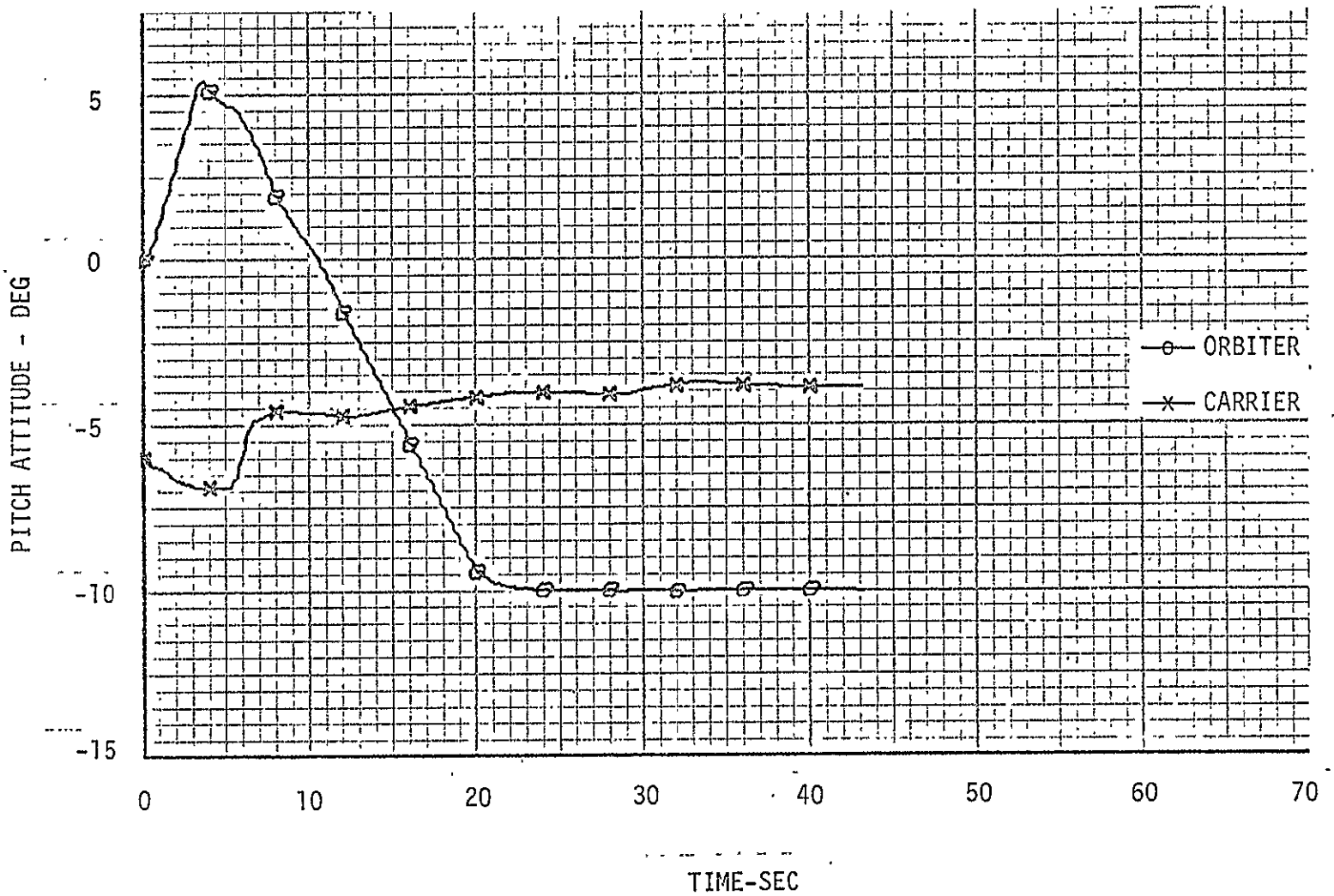

FIGURE 16
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @63.9% L_B, 150000 LB ORBITER

LOCAL HORIZONTAL ROLL ATTITUDE TIME HISTORIES

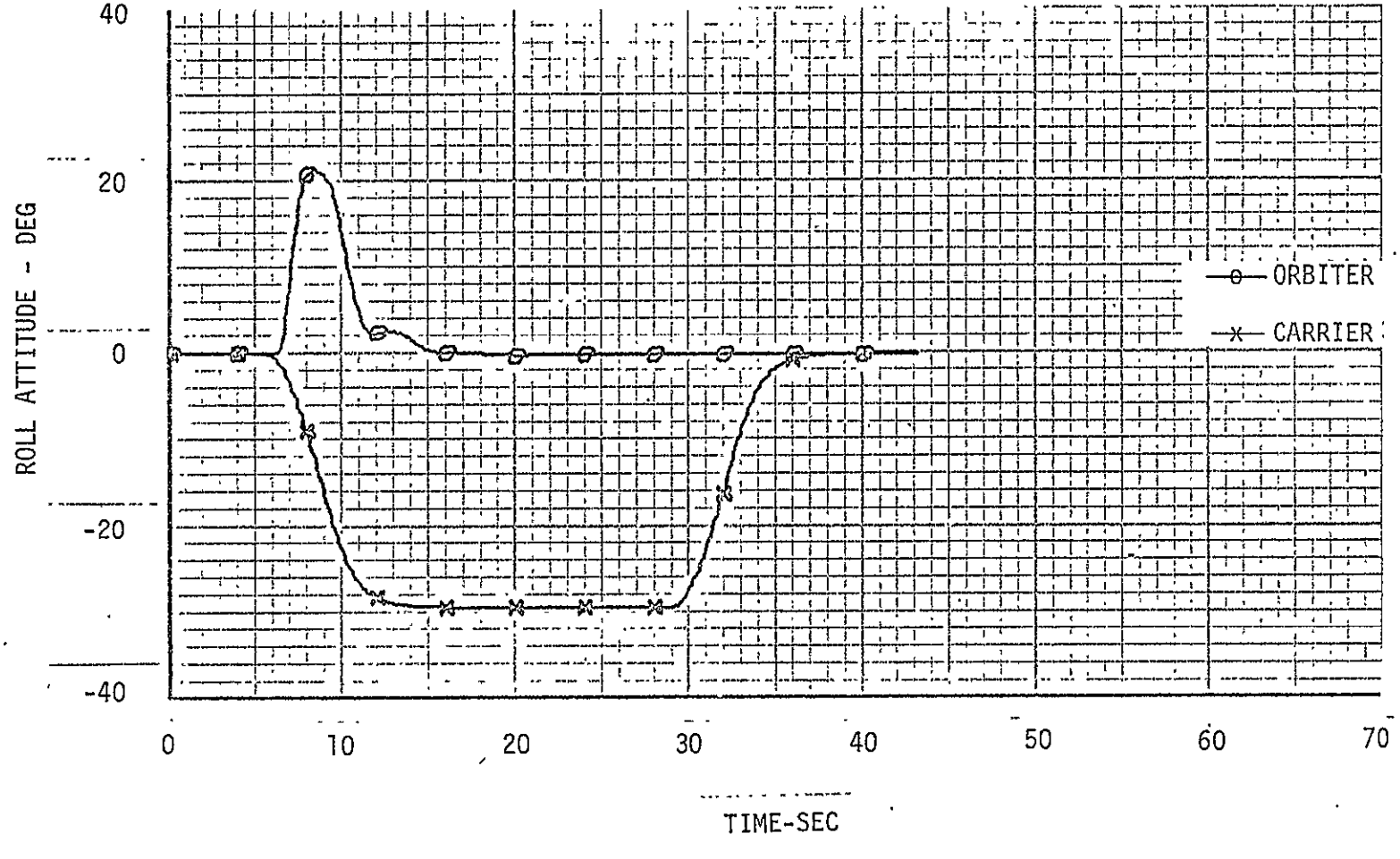

FIGURE 17
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

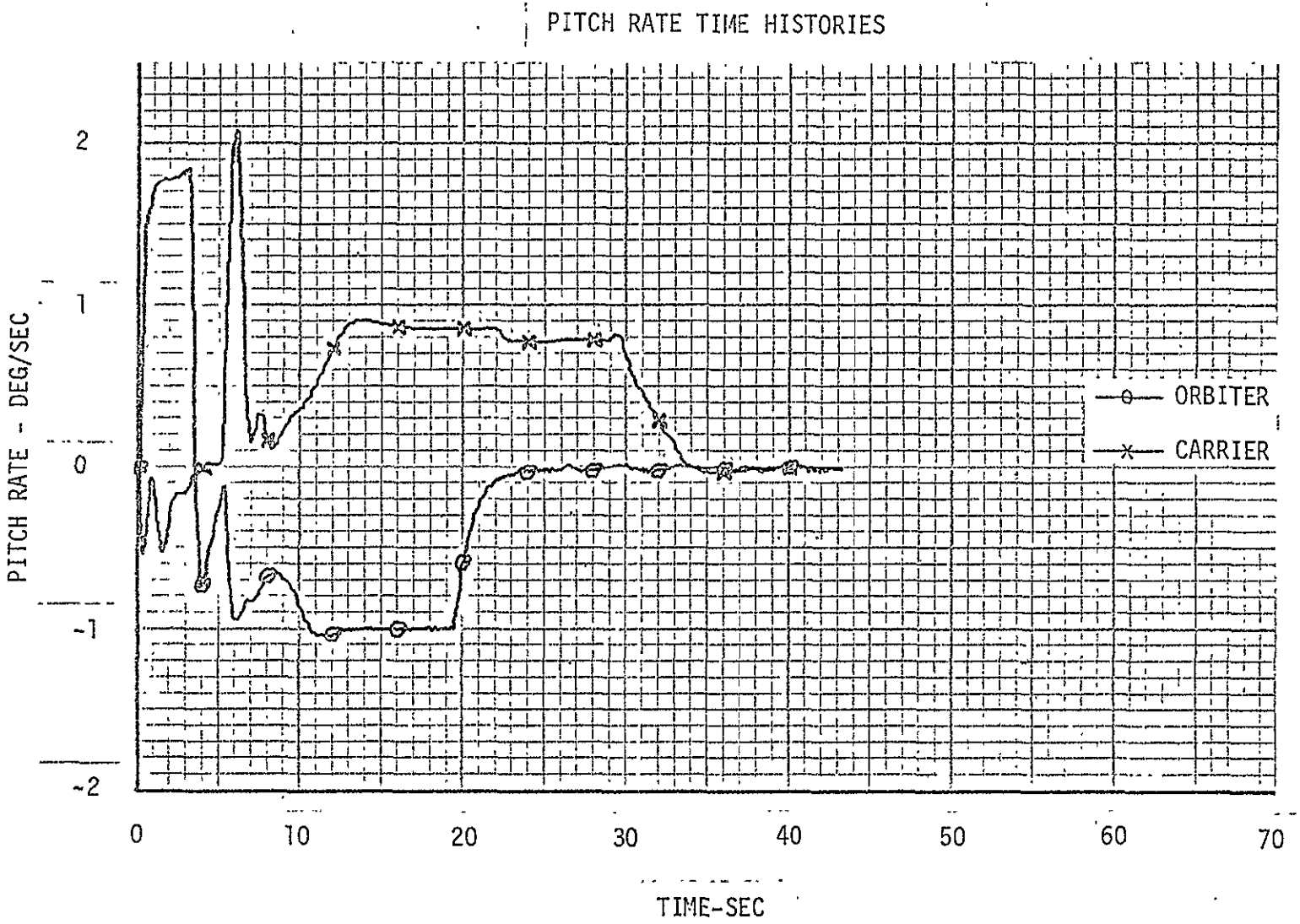

FIGURE 18
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

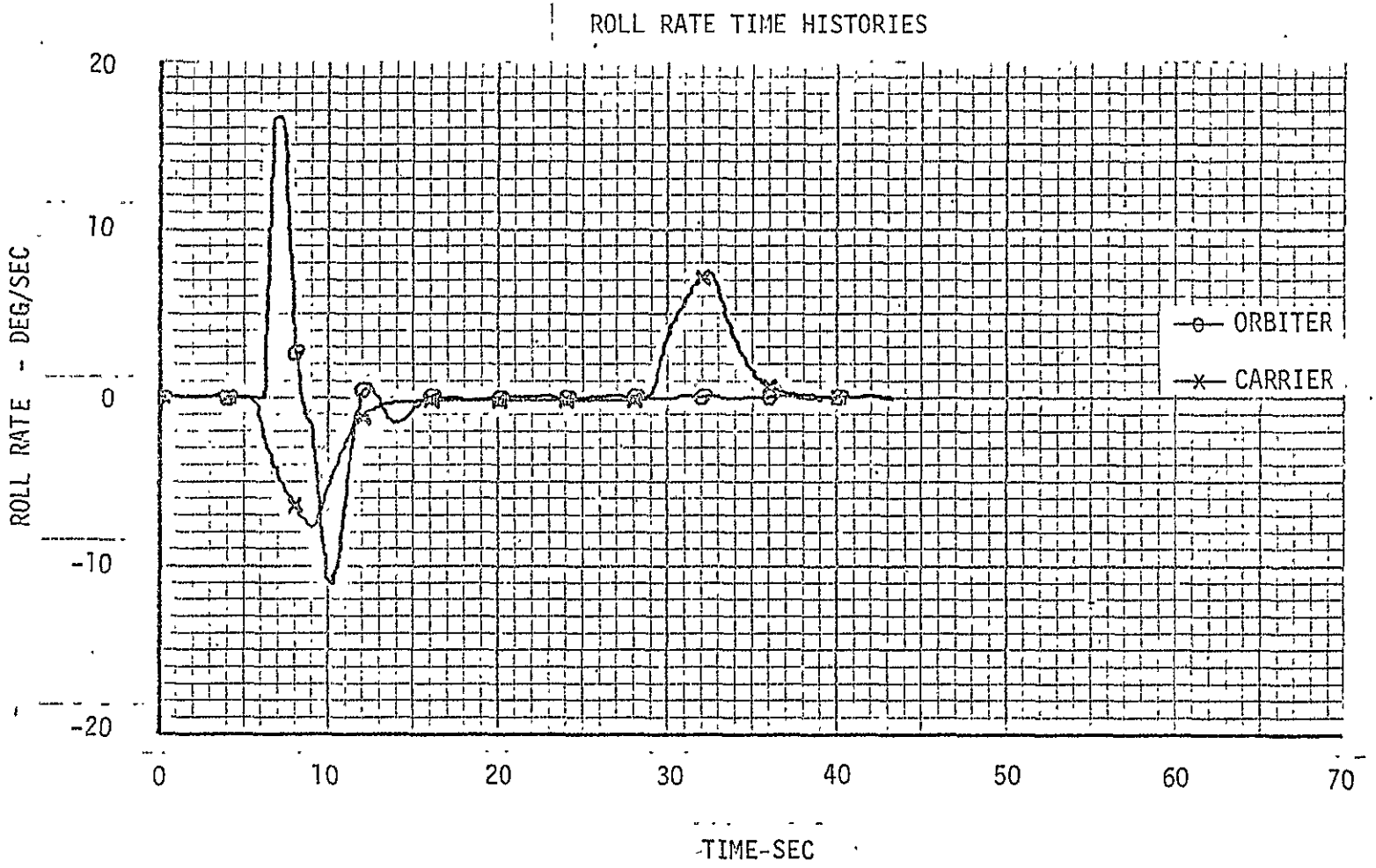

FIGURE 19
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

YAW RATE TIME HISTORIES

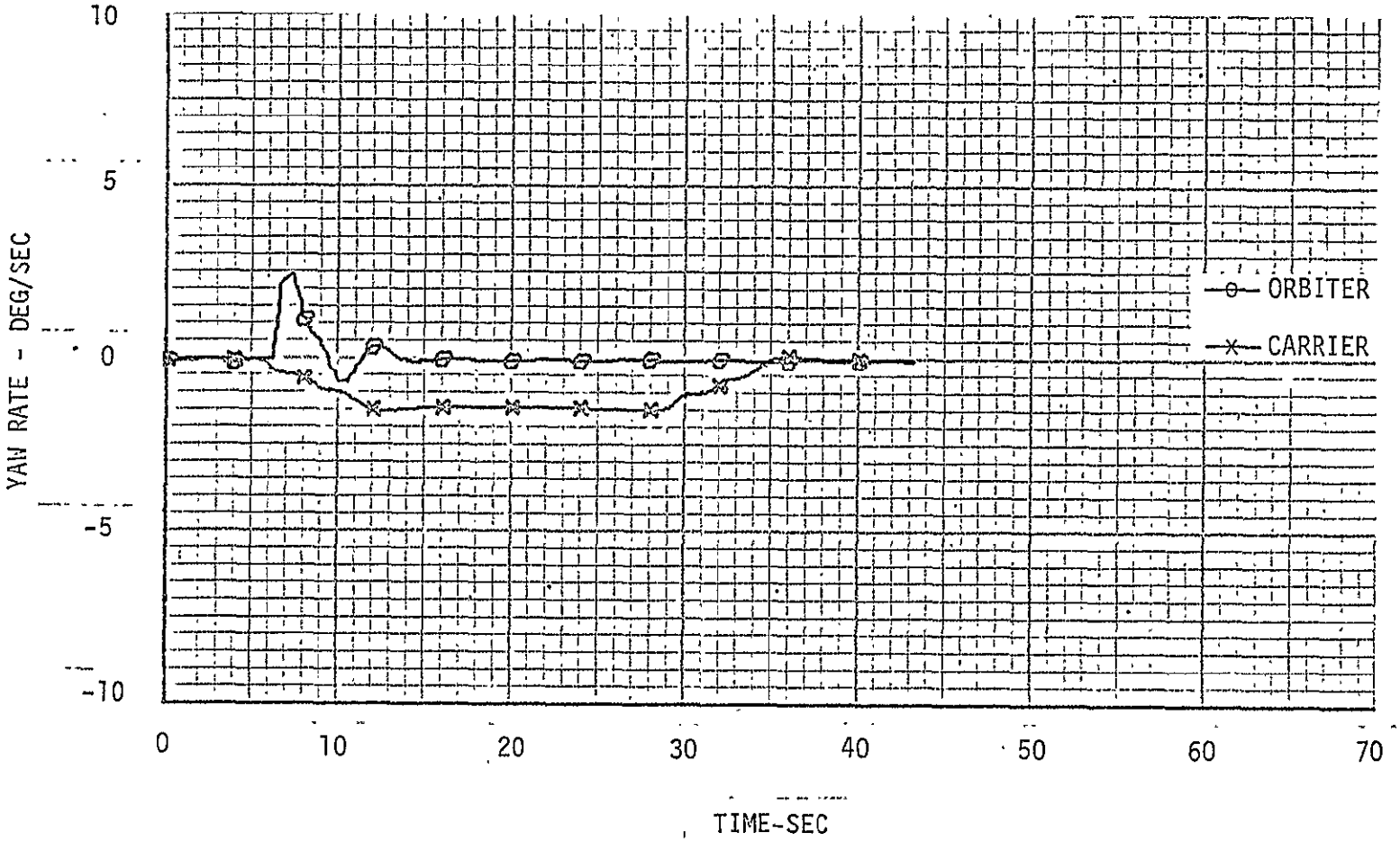

FIGURE 20
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

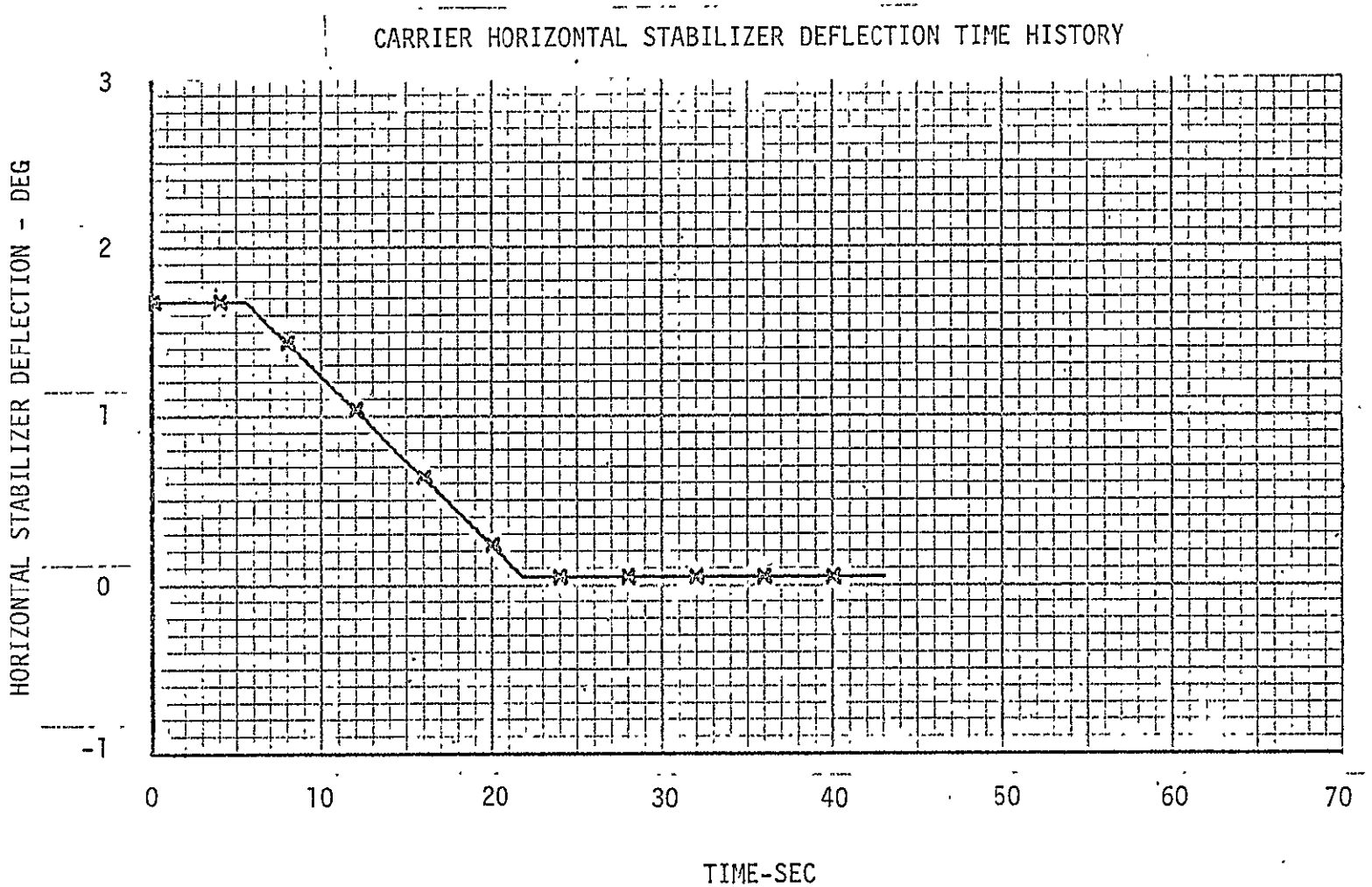

FIGURE 21
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

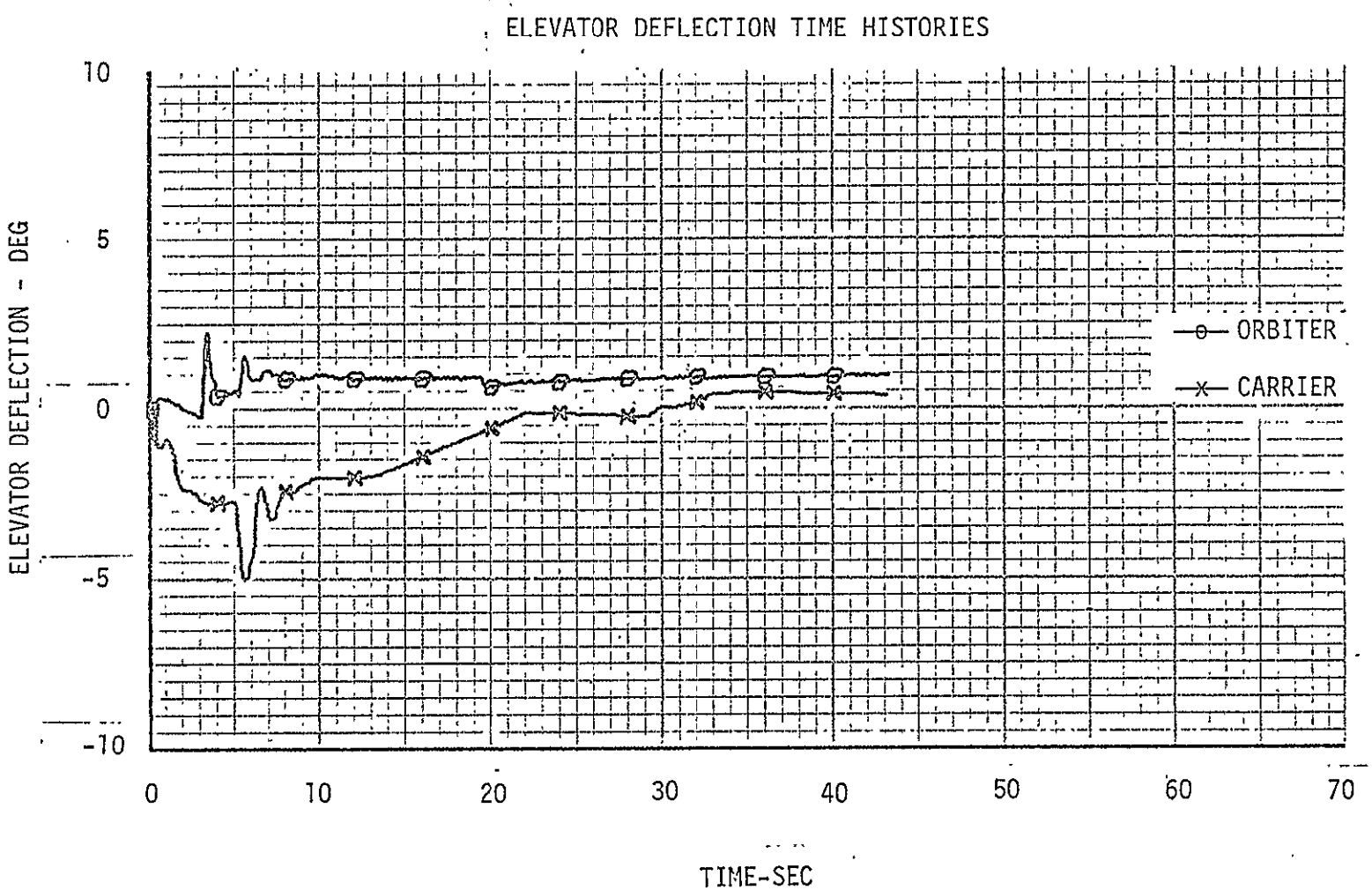

FIGURE 22
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

AILERON DEFLECTION TIME HISTORIES

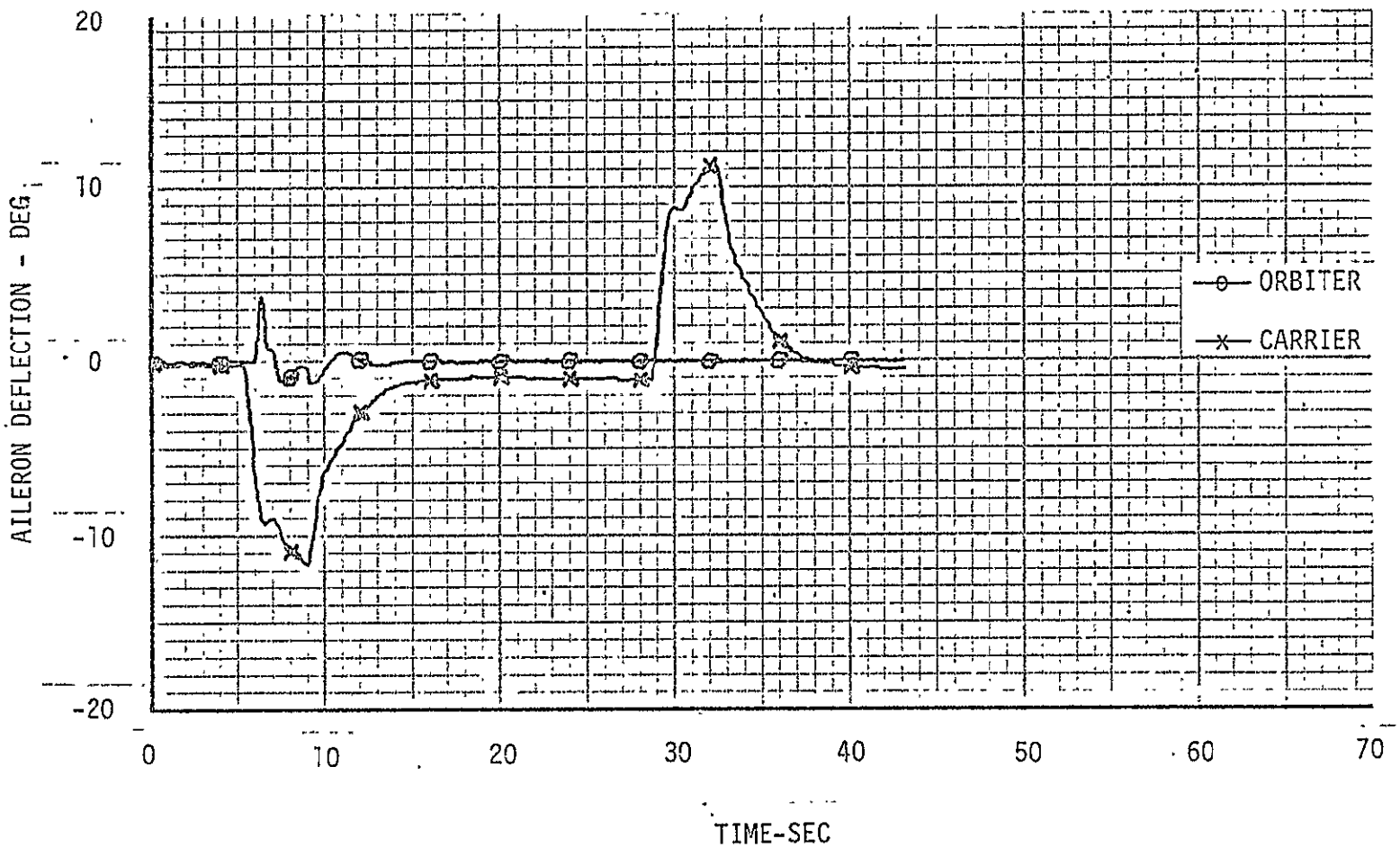

FIGURE 23
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

RUDDER DEFLECTION TIME HISTORIES

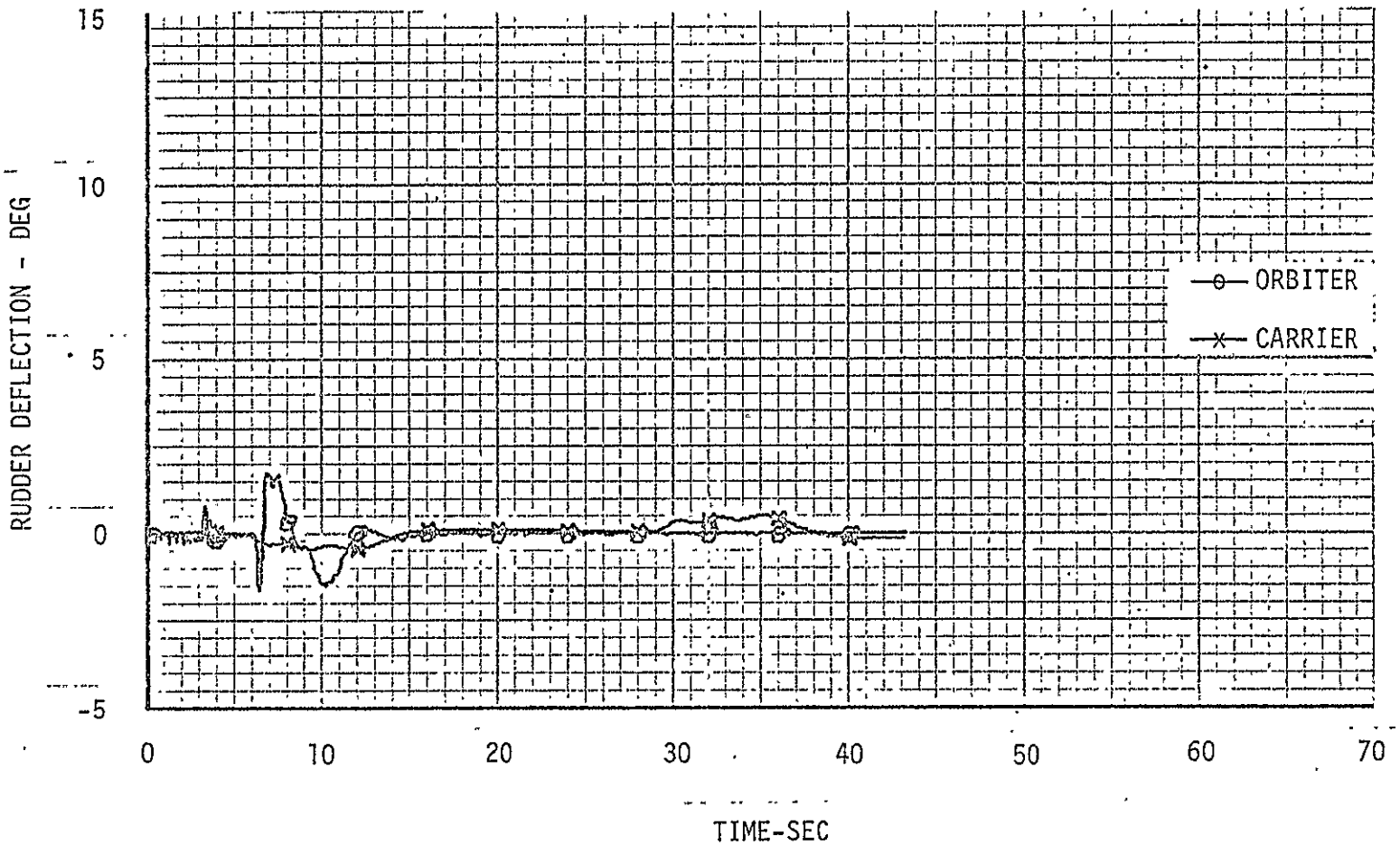

FIGURE 24
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

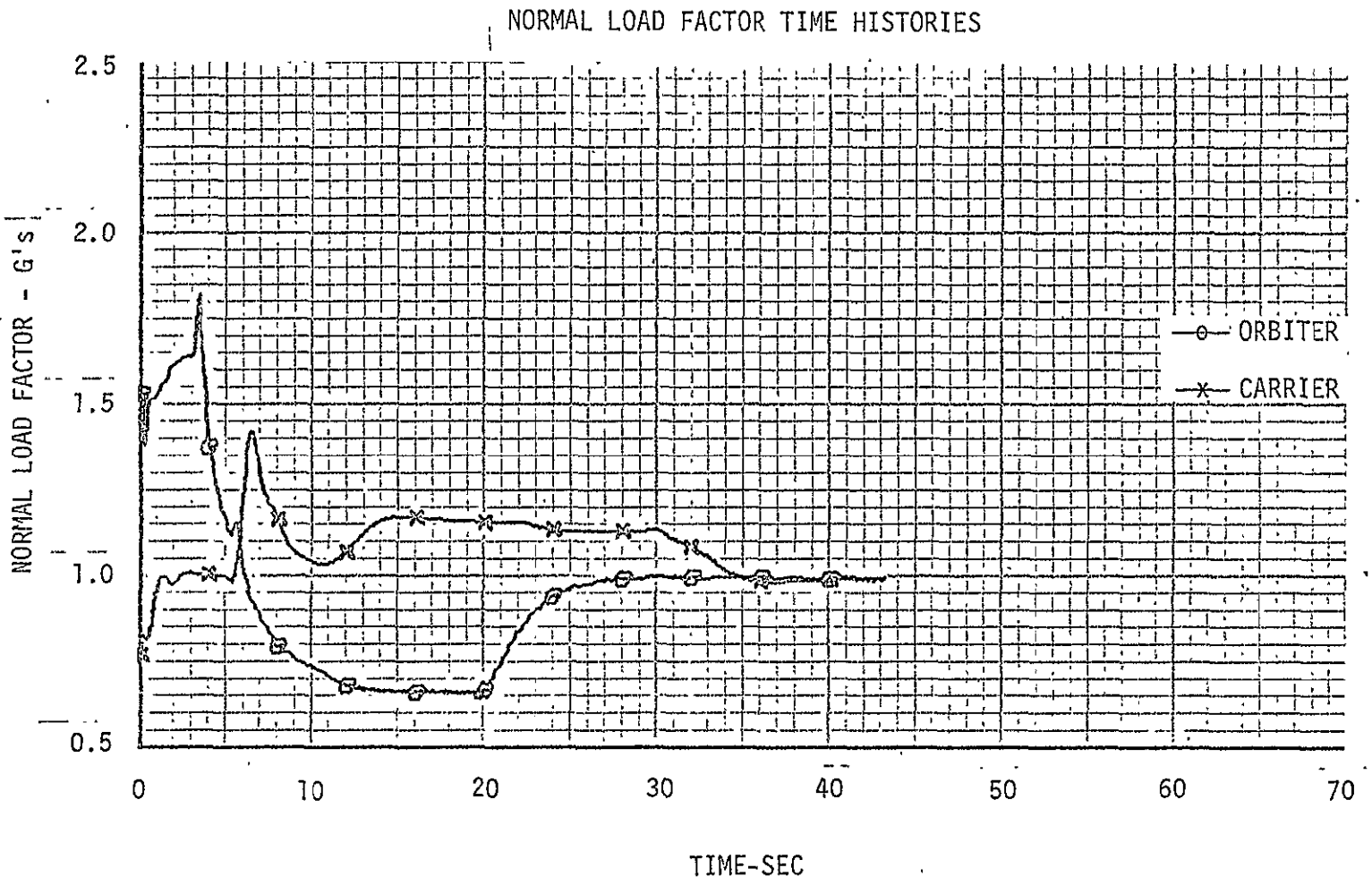

FIGURE 25
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

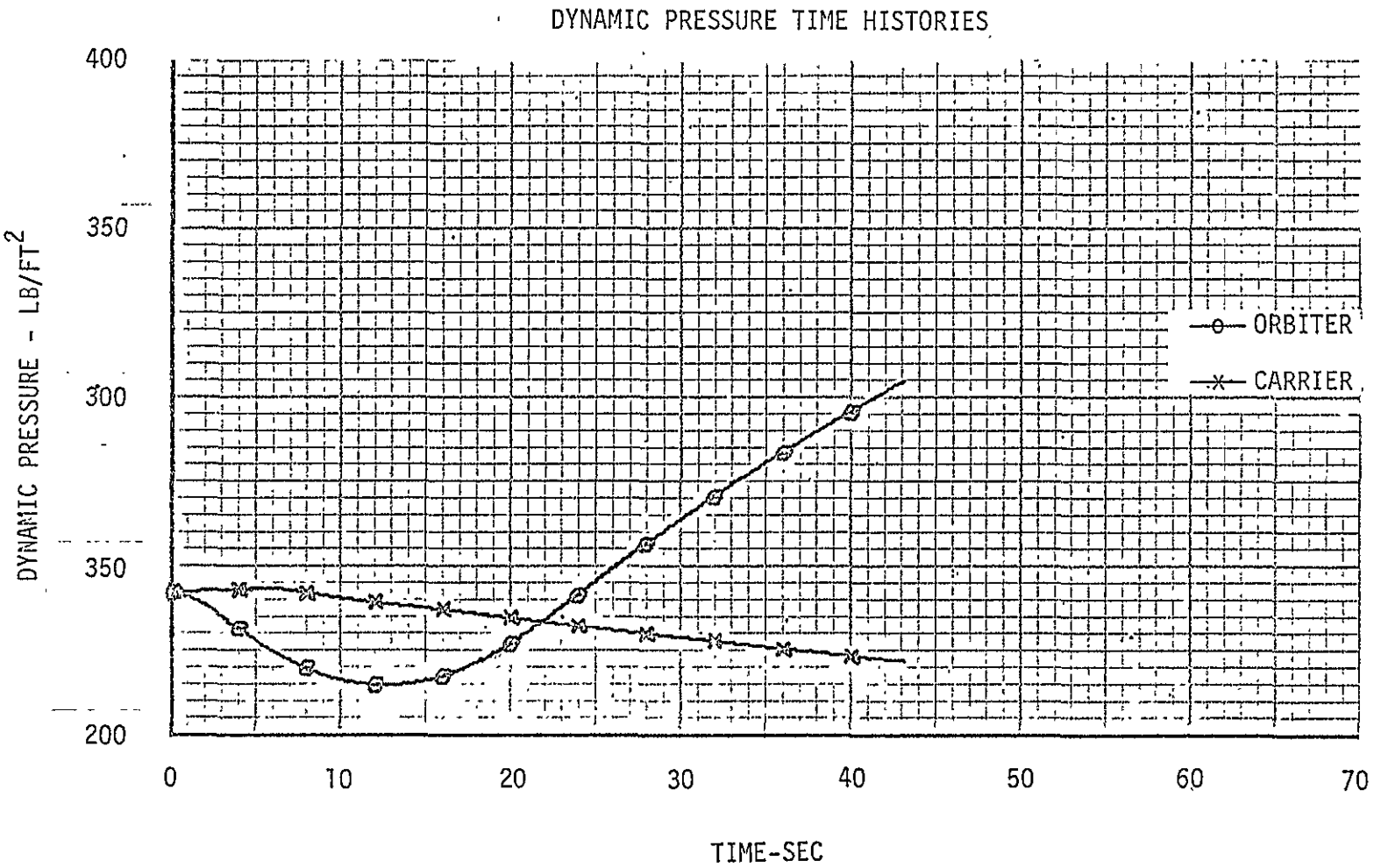

FIGURE 26
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

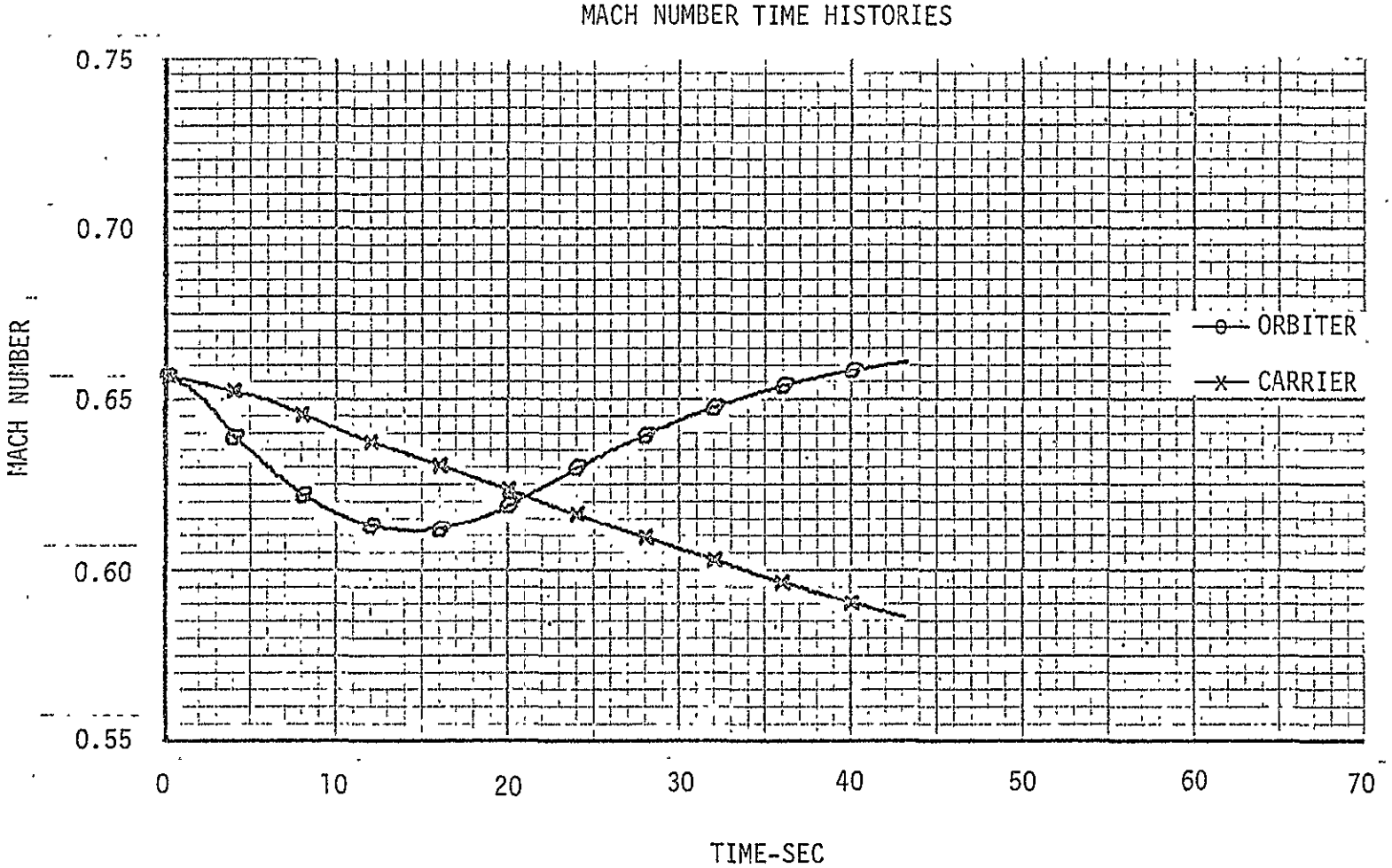

FIGURE 27
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

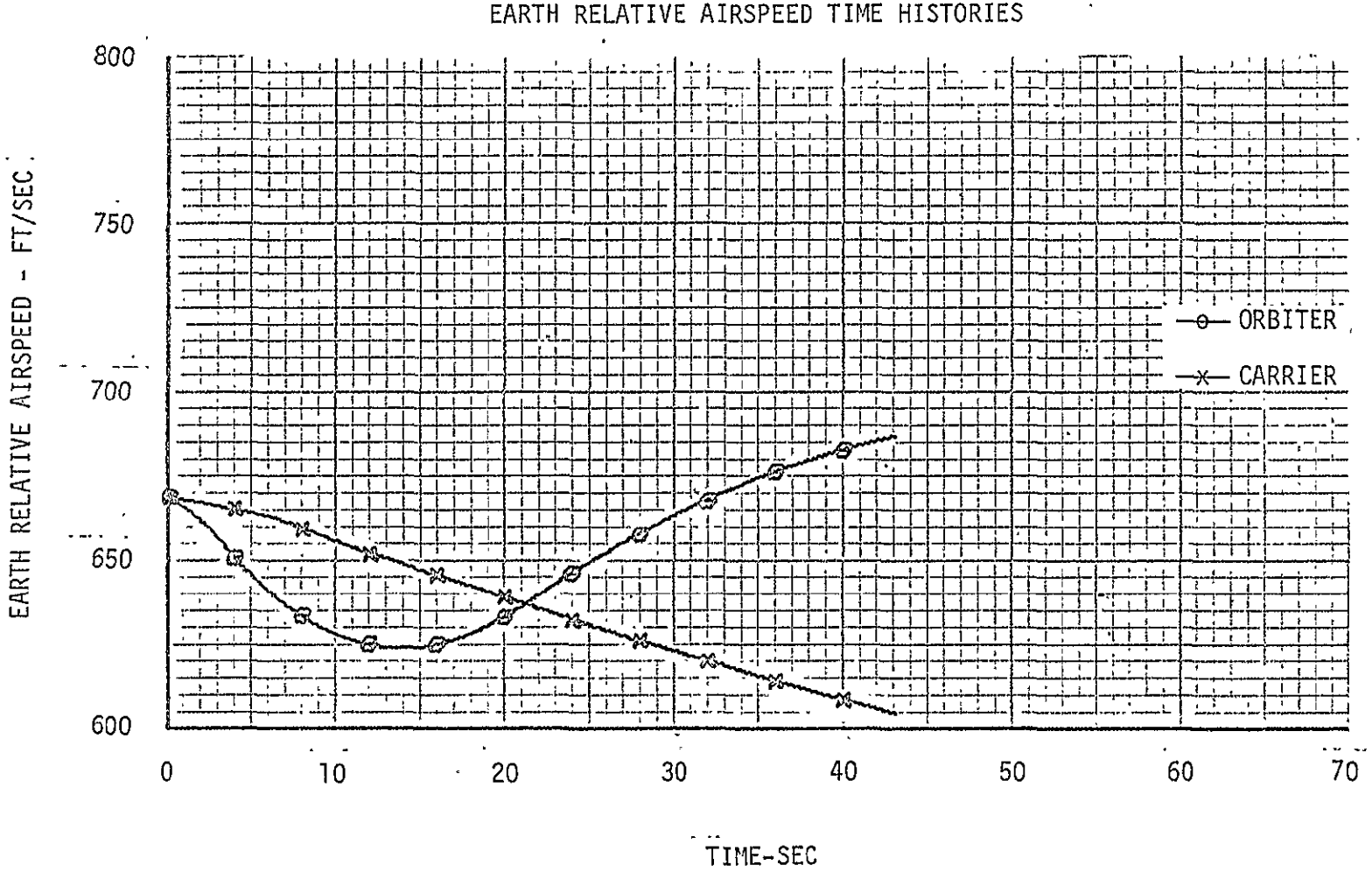

FIGURE 28
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

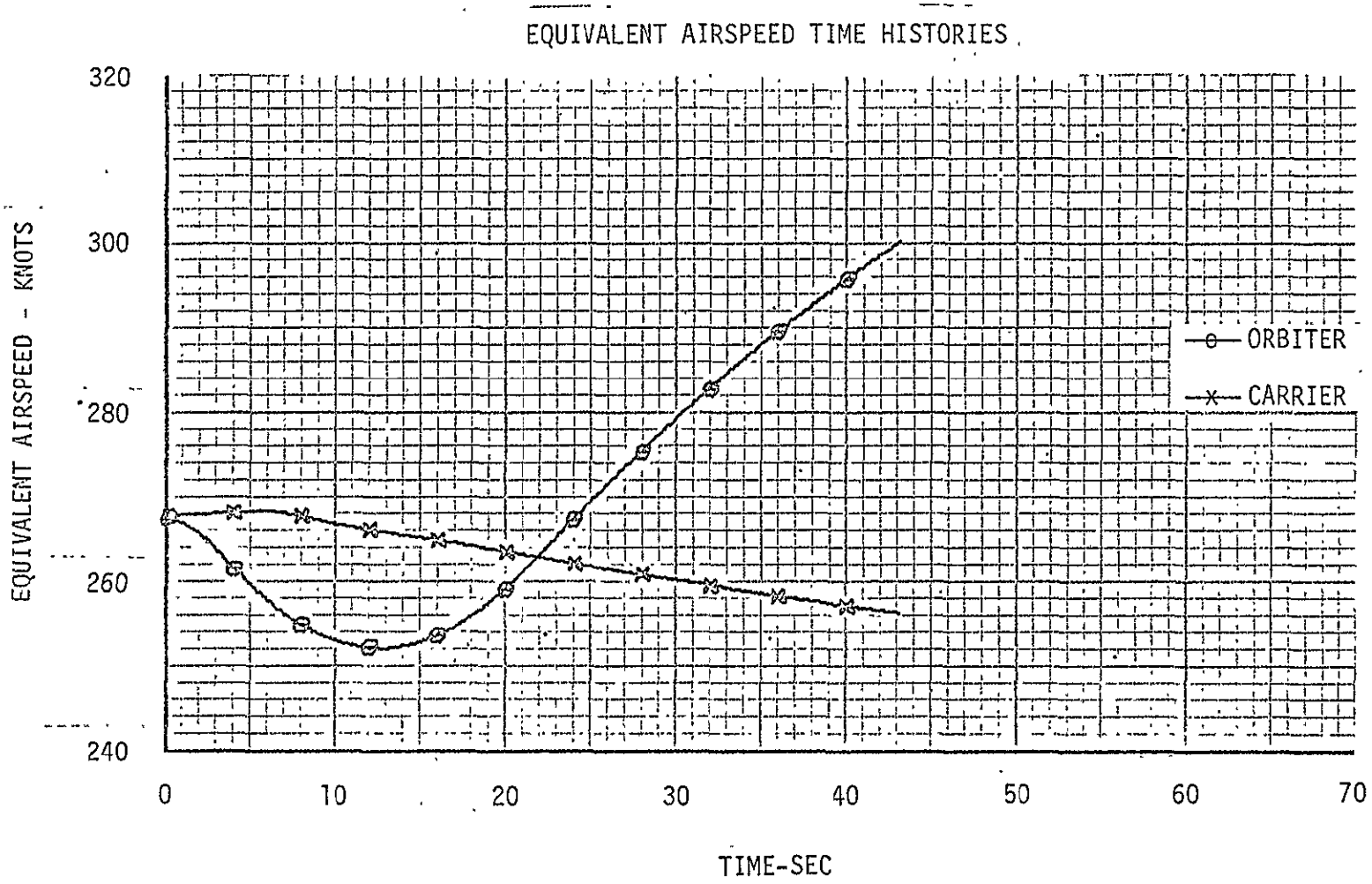

FIGURE 29
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

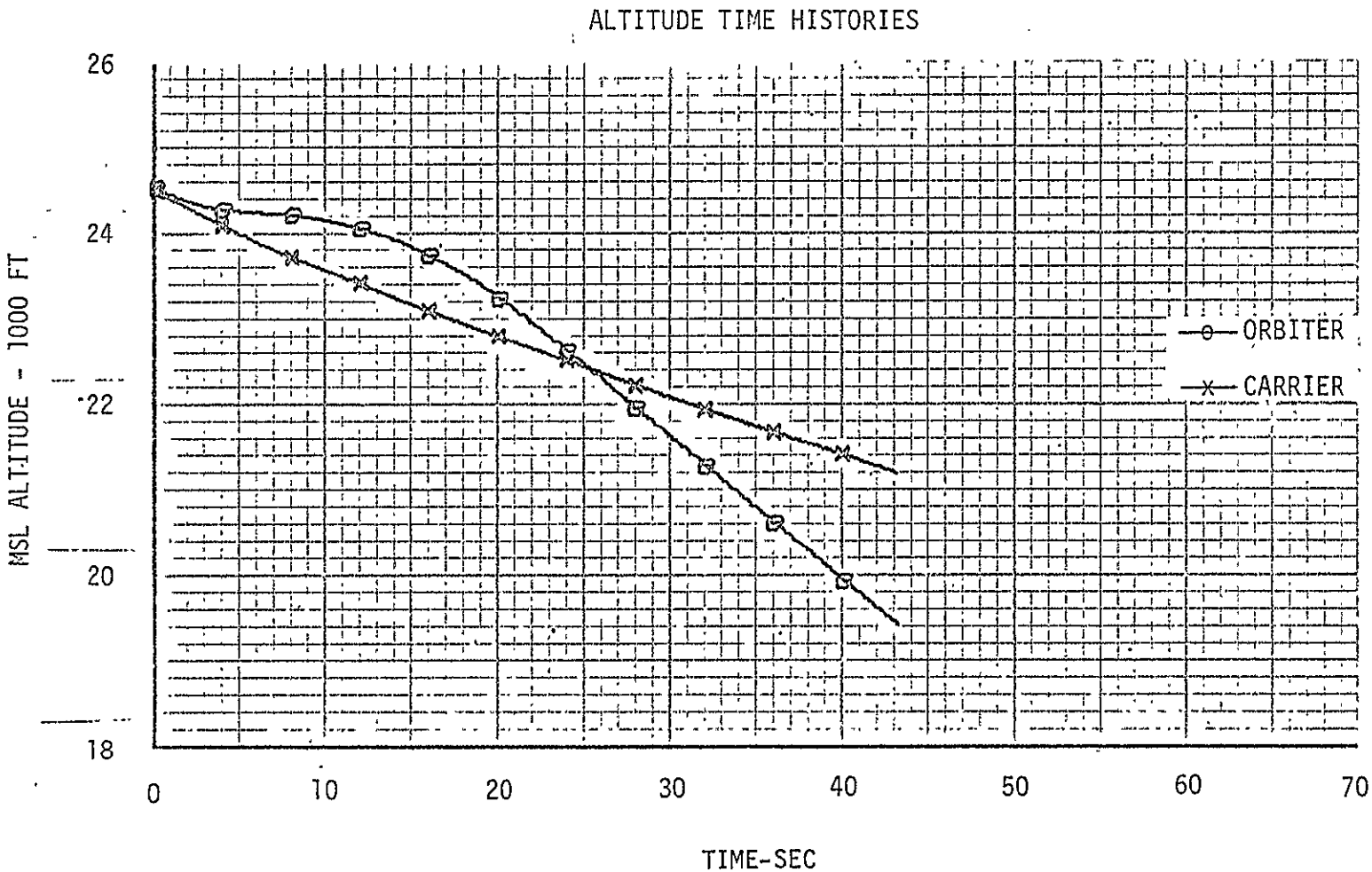

FIGURE 30
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 63.9% L_B, 150000 LB ORBITER

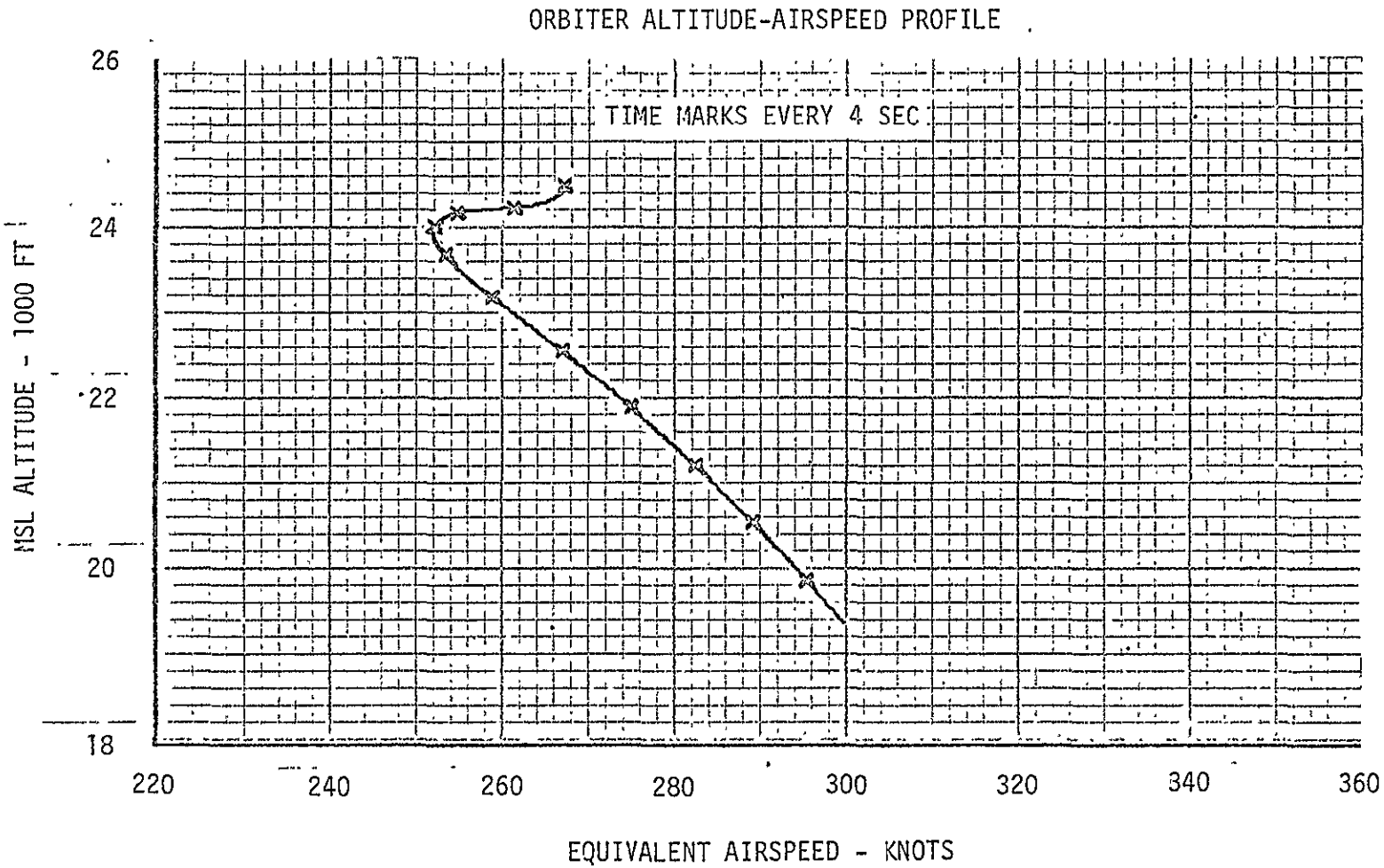

FIGURE 31
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

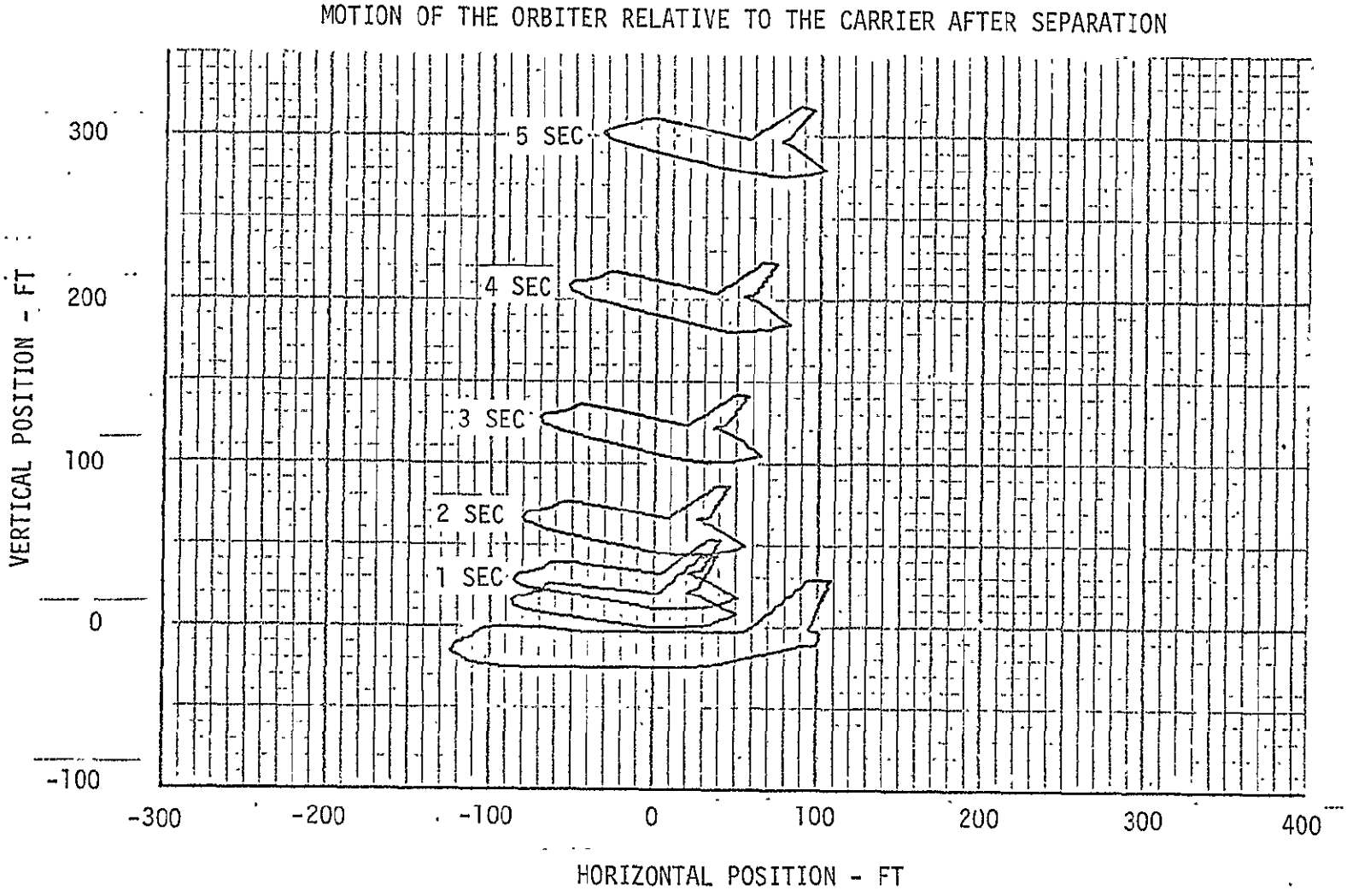

FIGURE 32
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

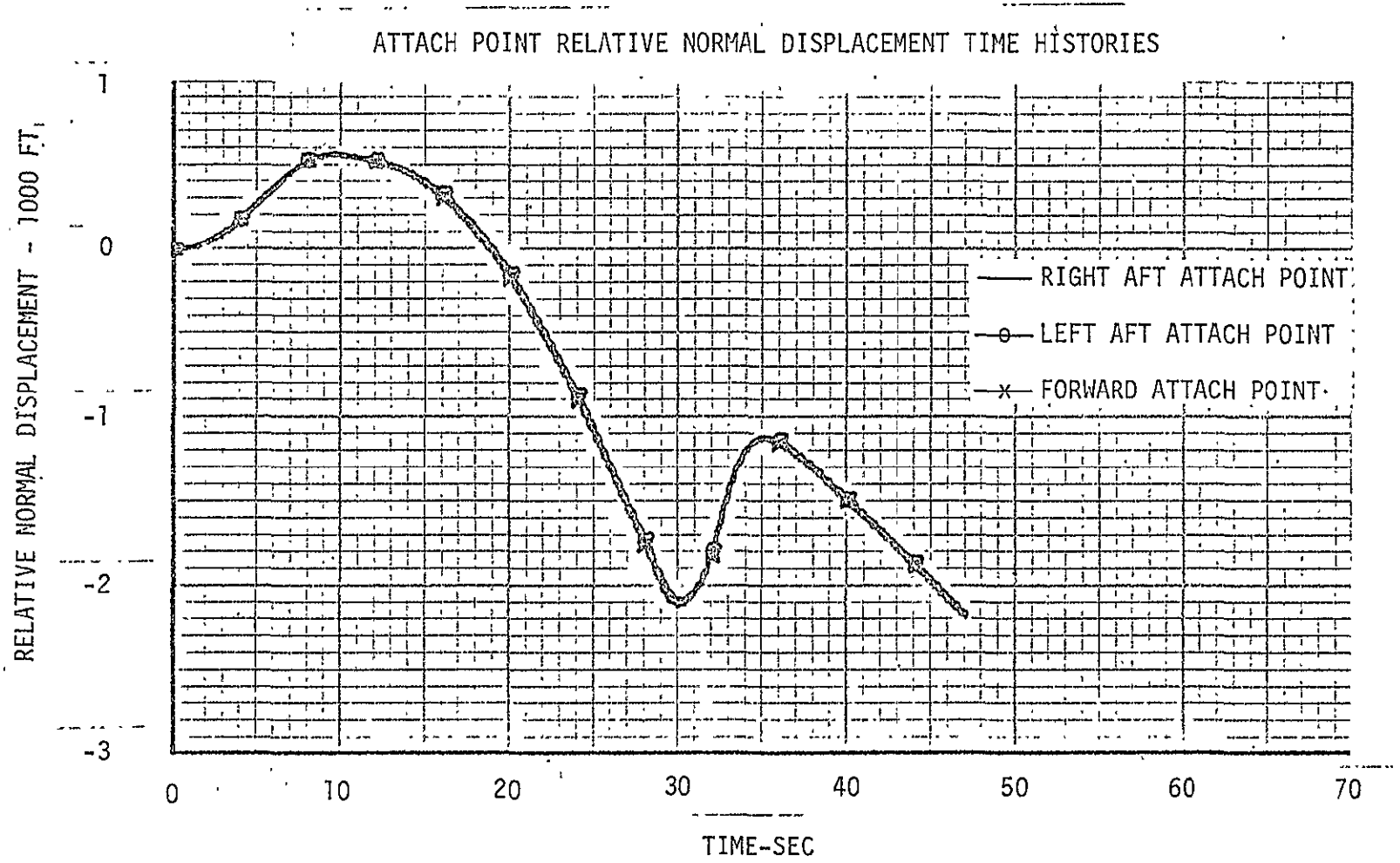

FIGURE 33
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

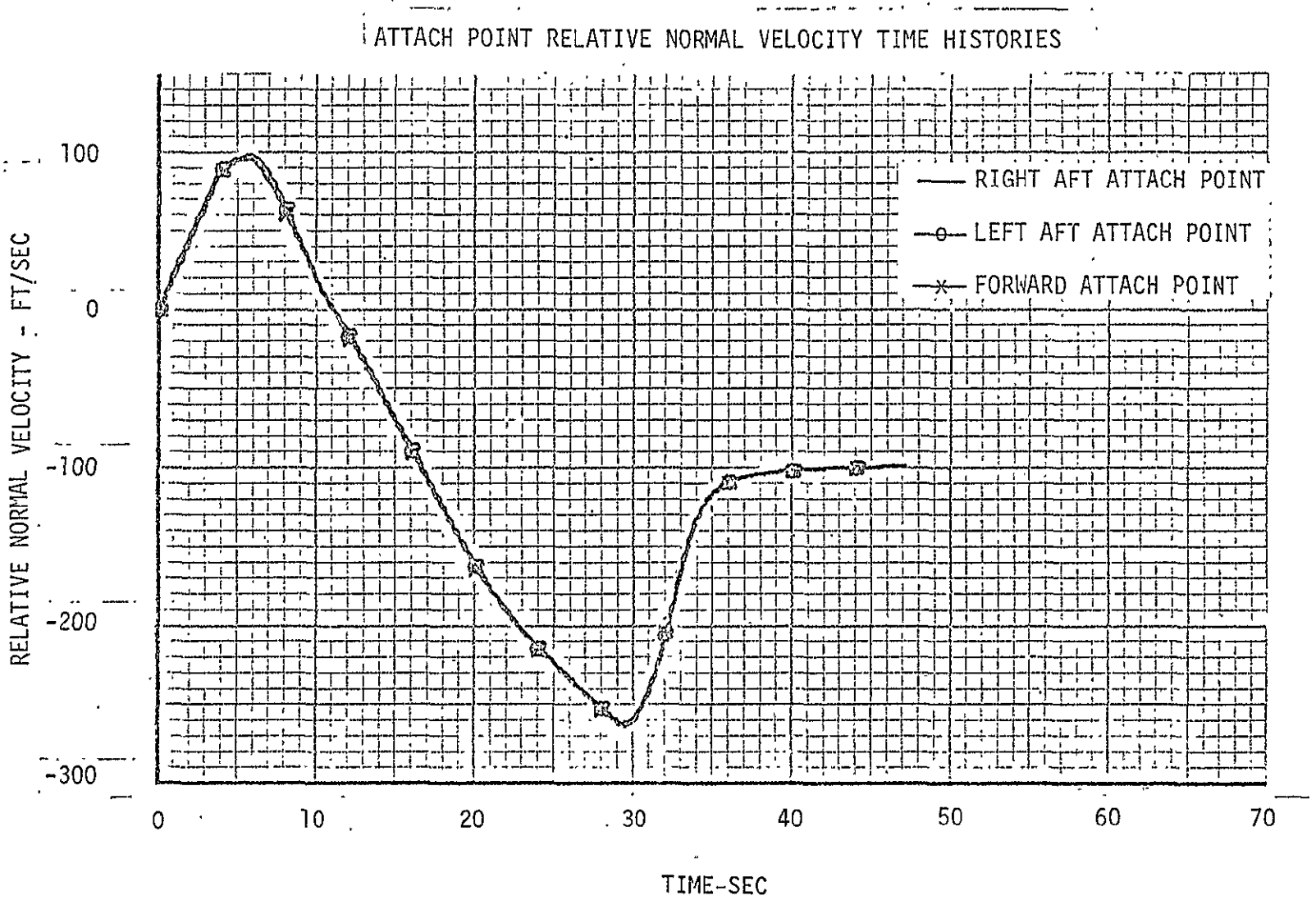

FIGURE 34
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

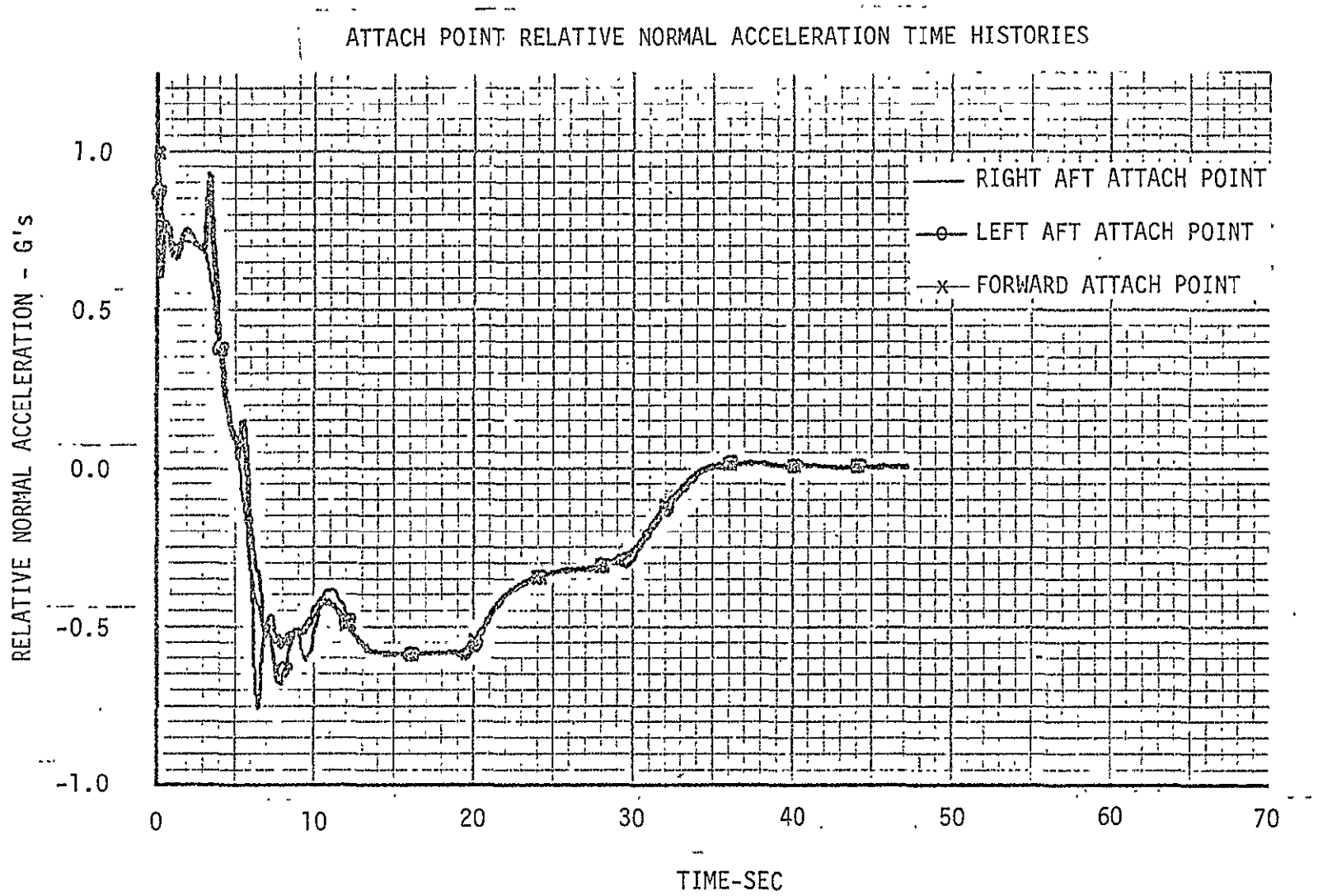

FIGURE 35
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

RELATIVE AXIAL ACCELERATION TIME HISTORY

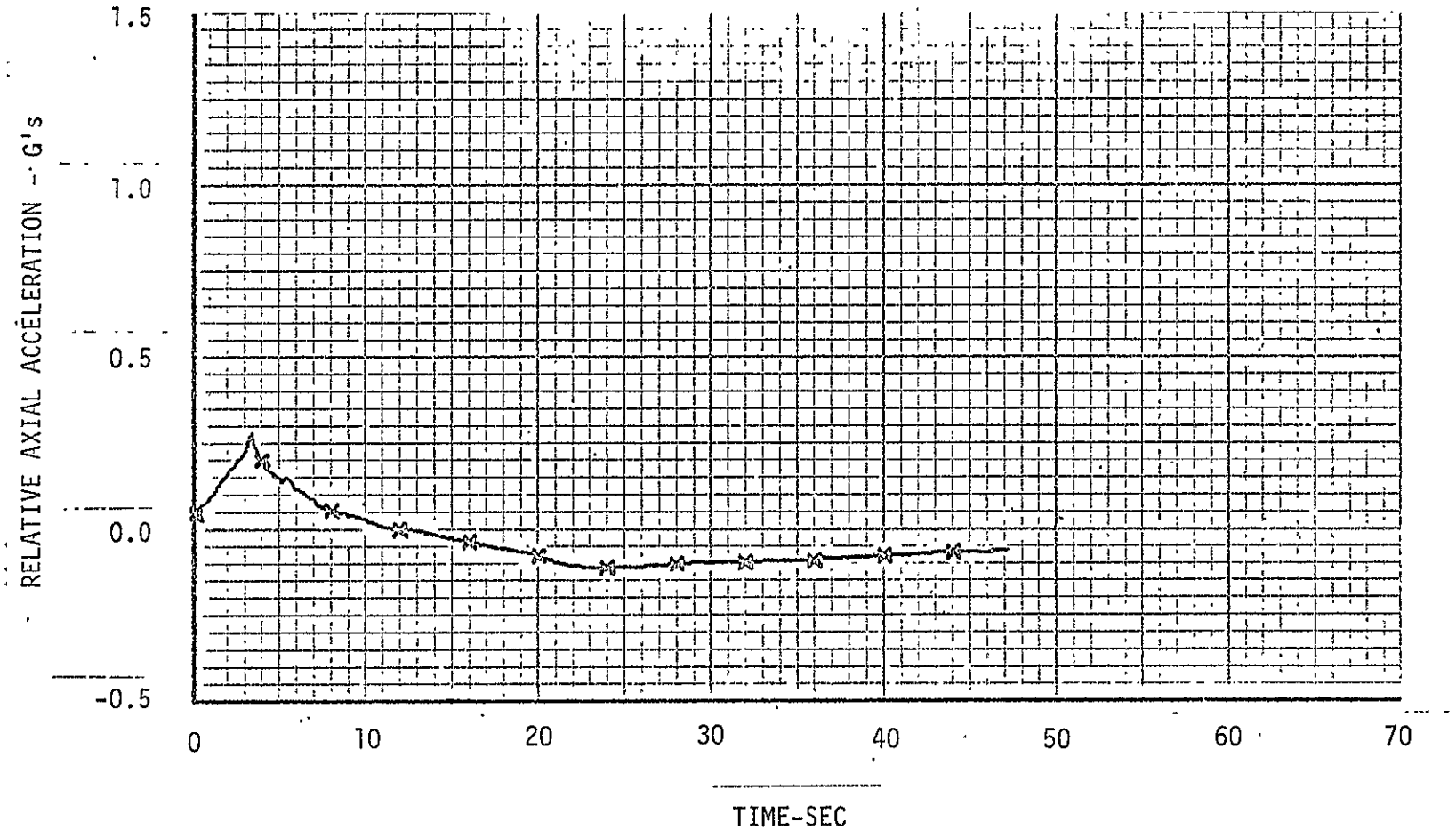

FIGURE 36
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

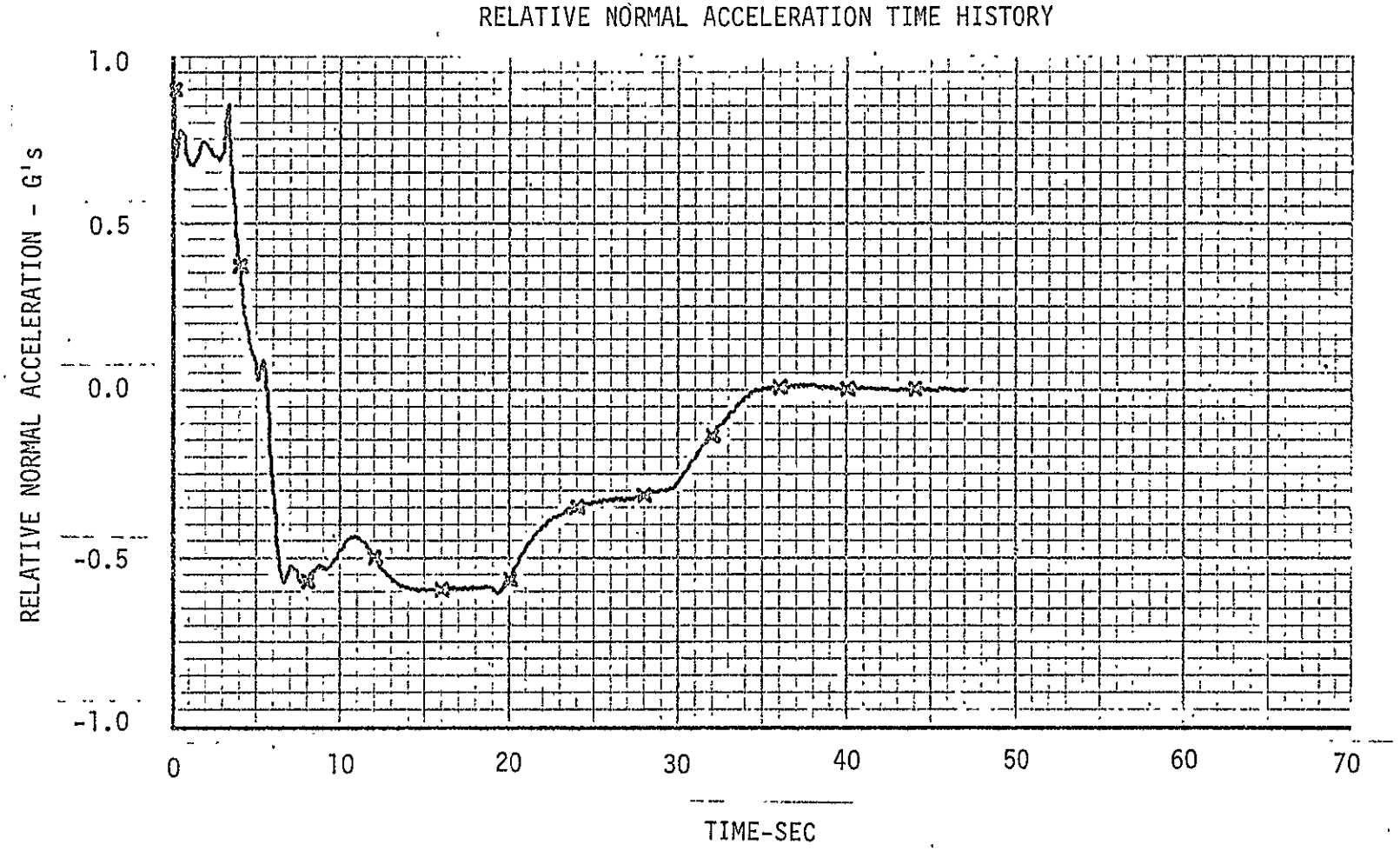

FIGURE 37
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

RELATIVE DOWNRANGE VERSUS RELATIVE CROSSRANGE

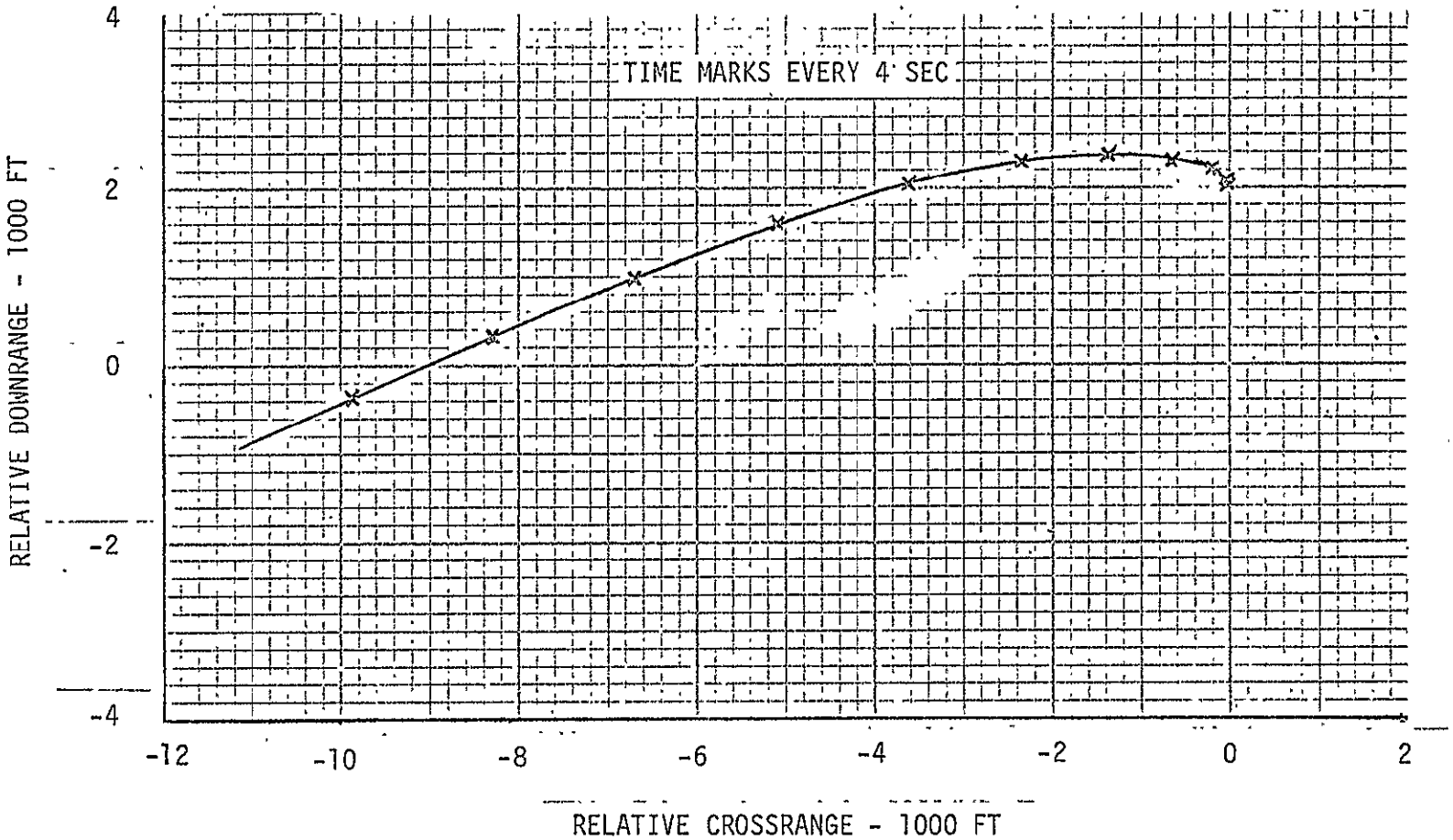

FIGURE 38
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

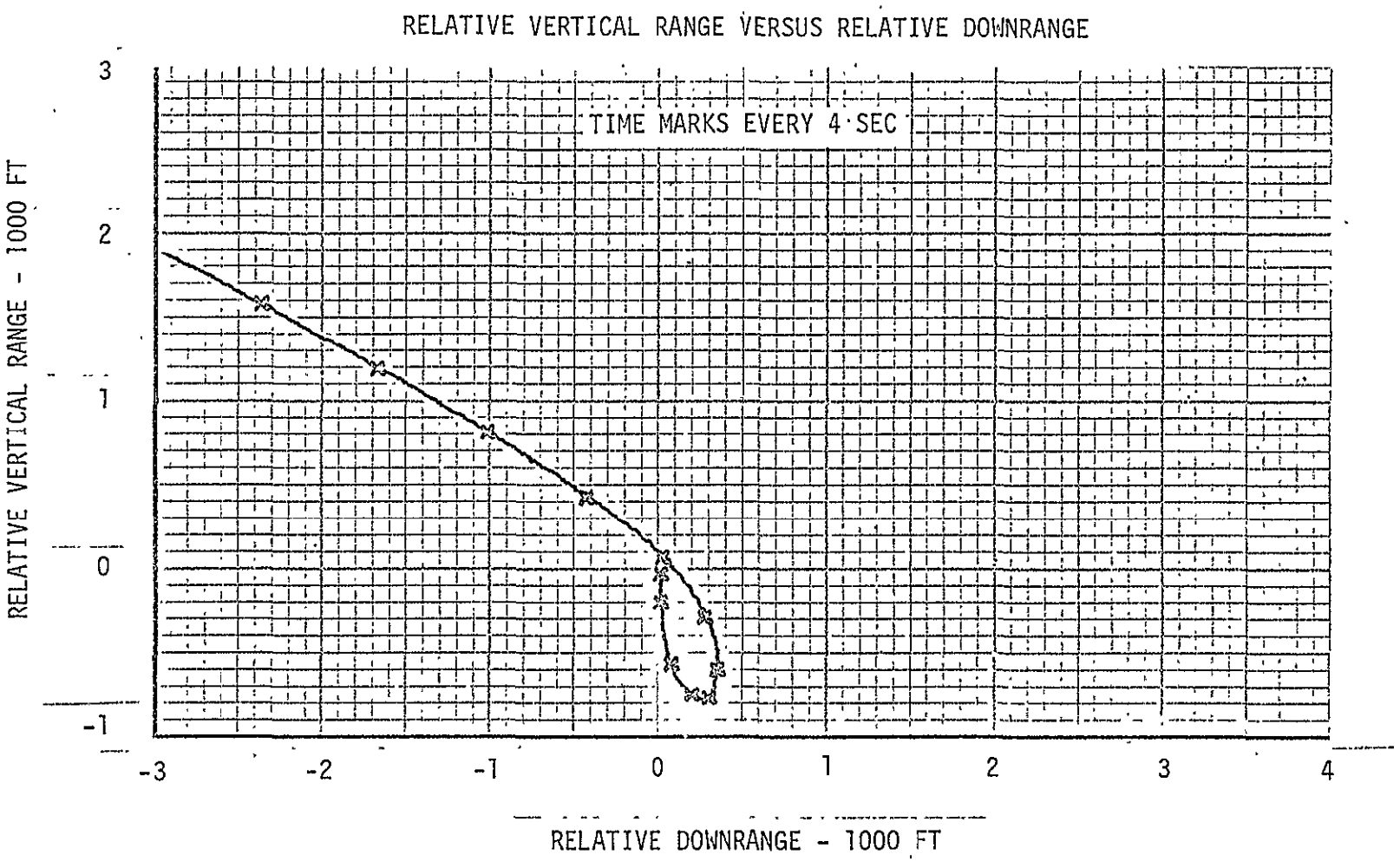

FIGURE 39
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

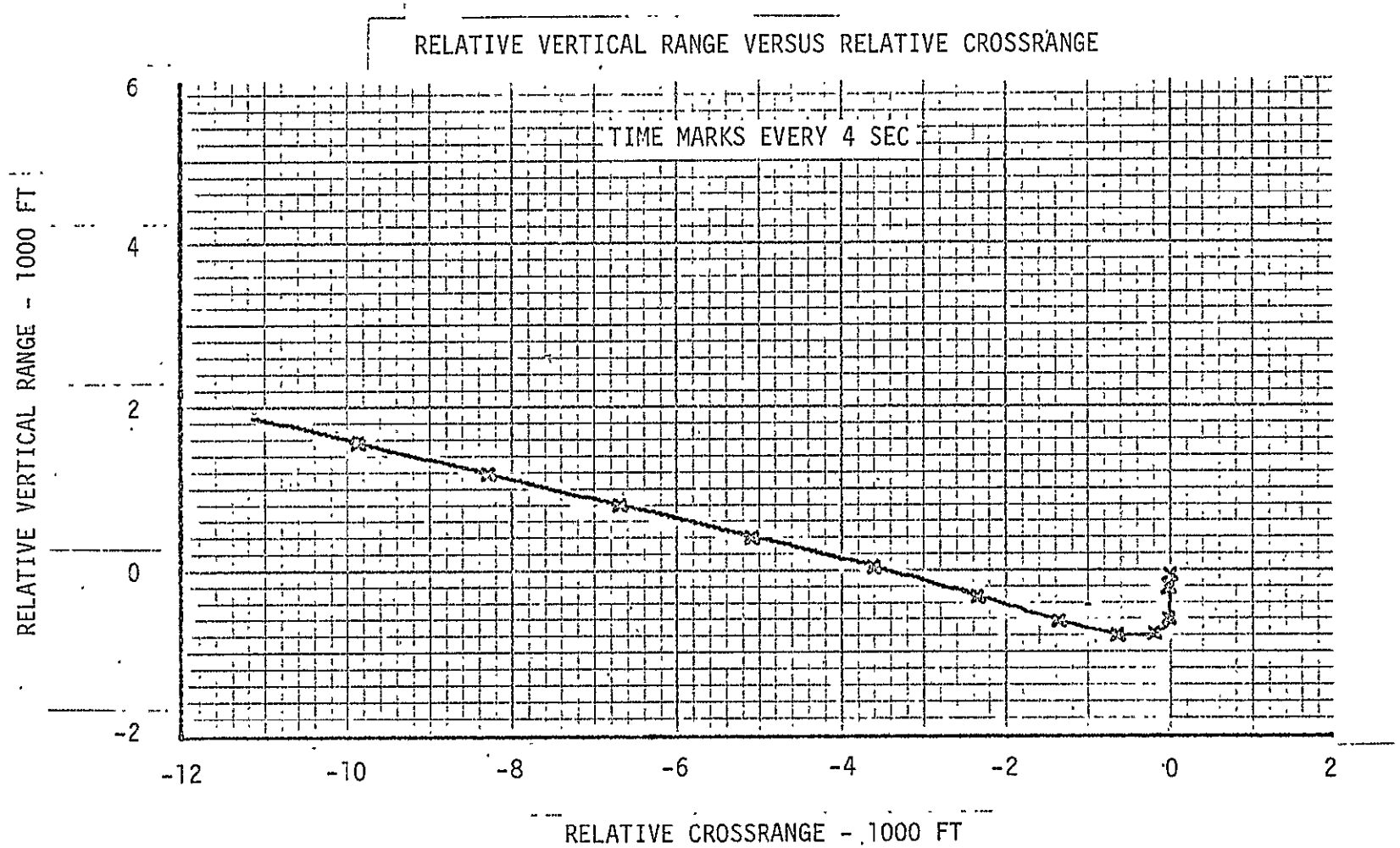

FIGURE 40
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

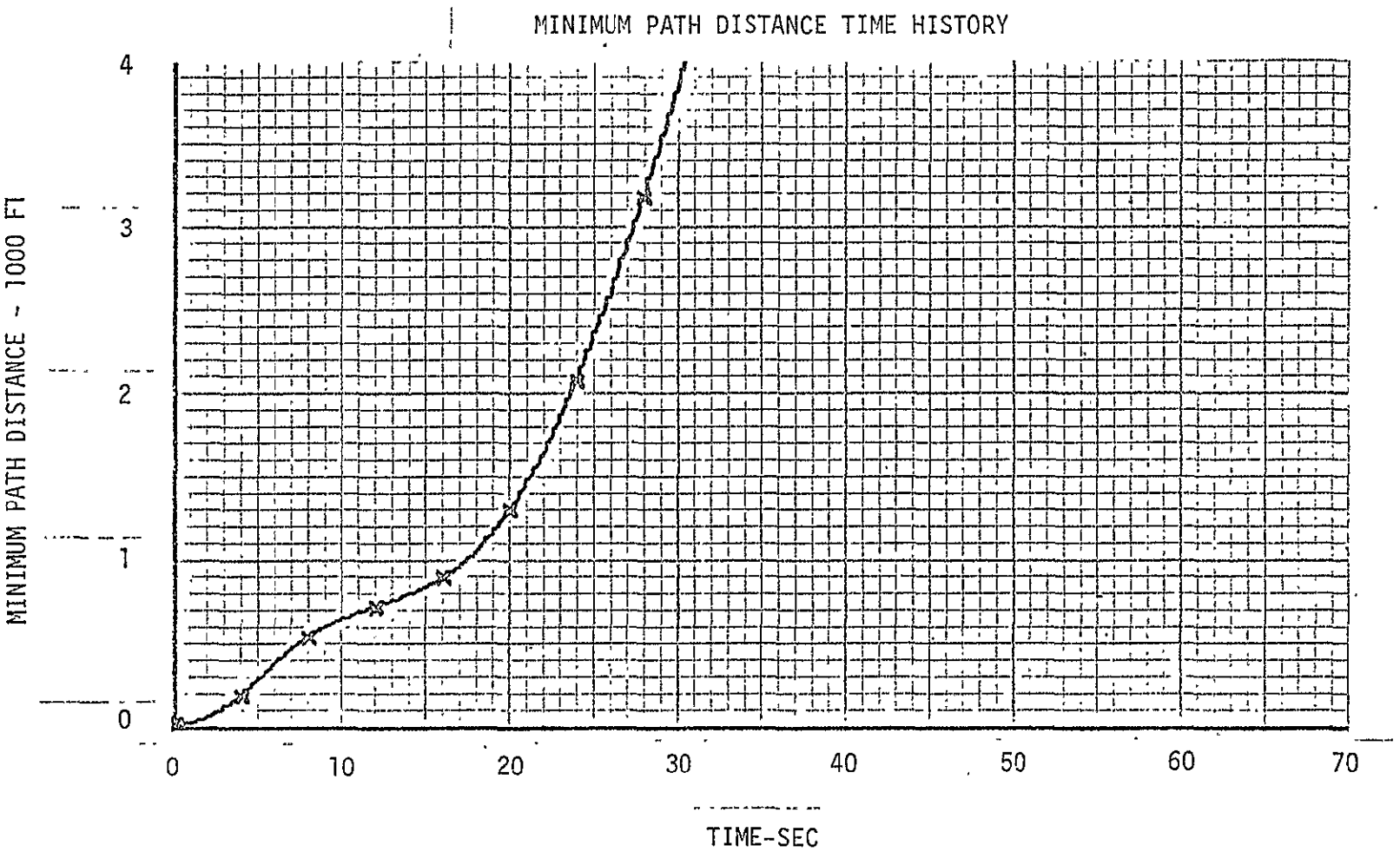

FIGURE 41
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

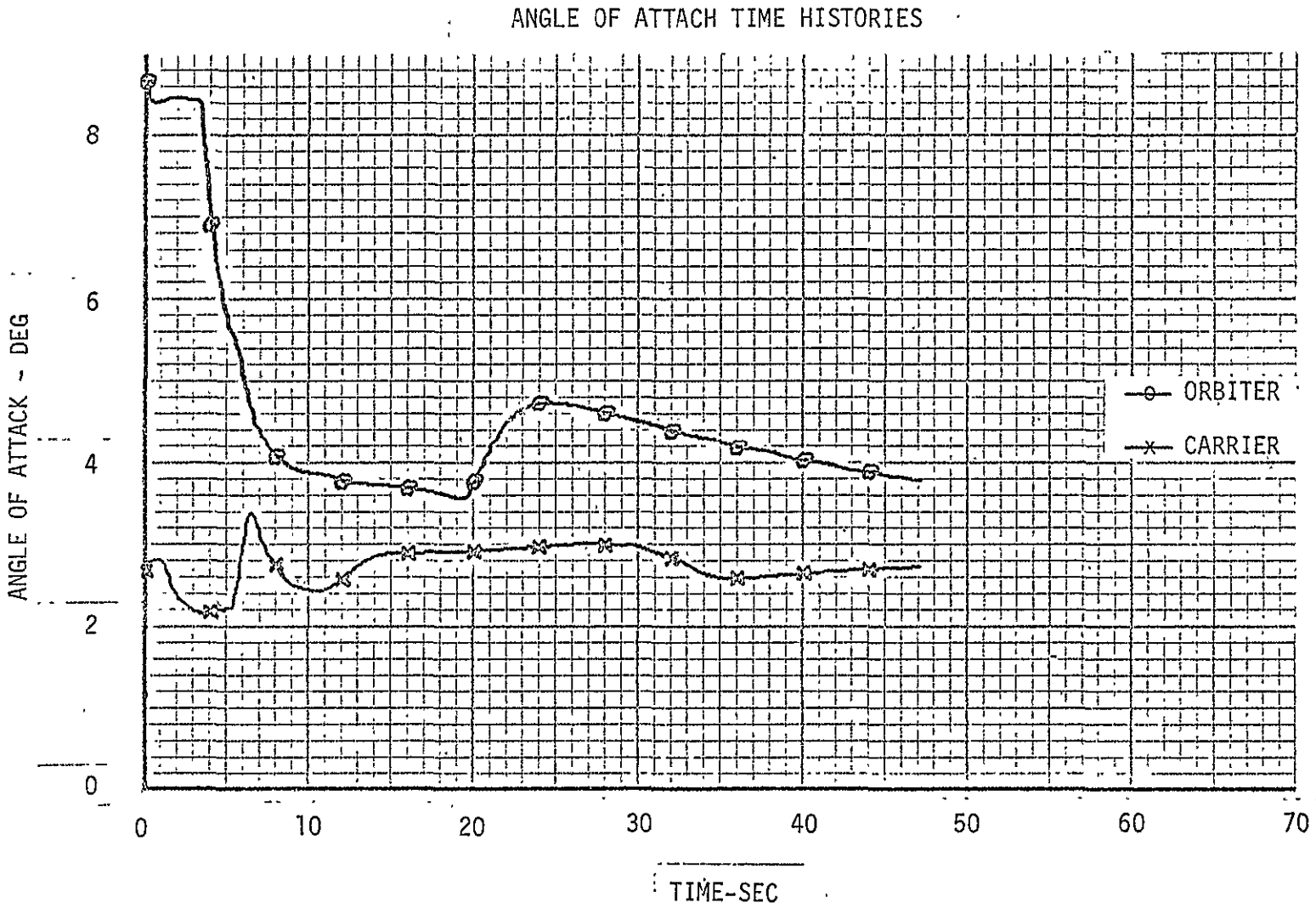

FIGURE 42
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

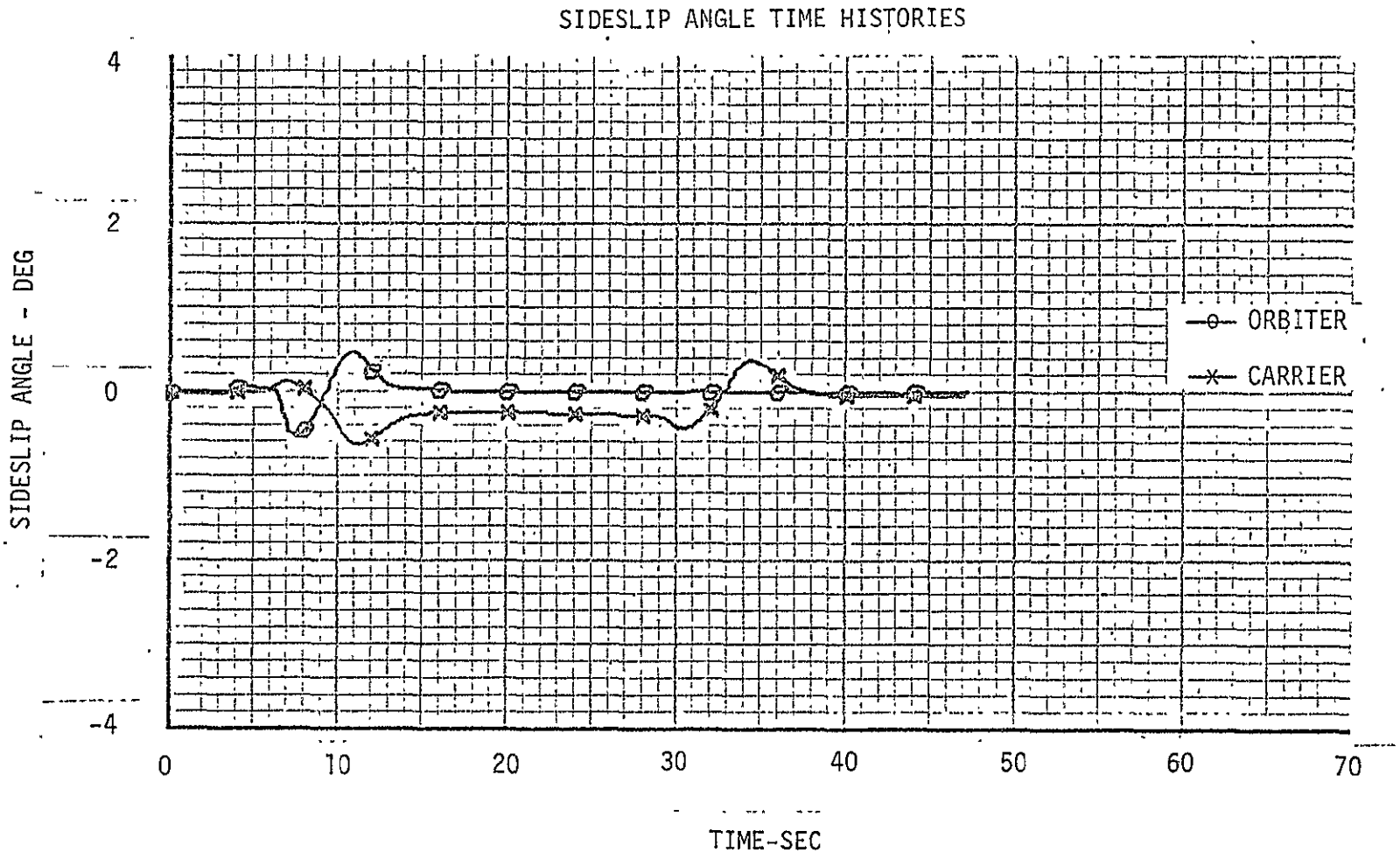

FIGURE 43
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

FLIGHT PATH ANGLE TIME HISTORIES

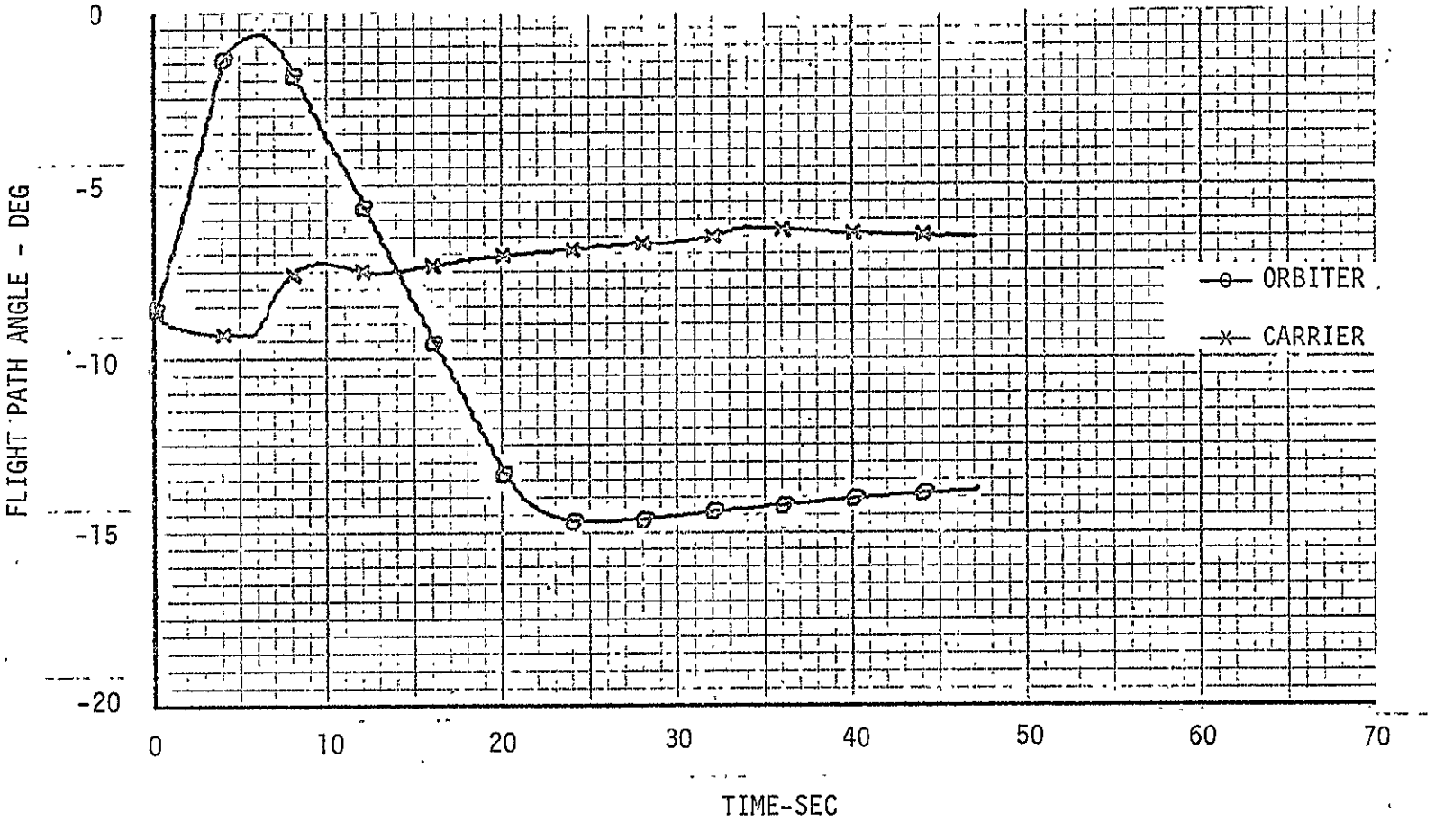

FIGURE 44
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

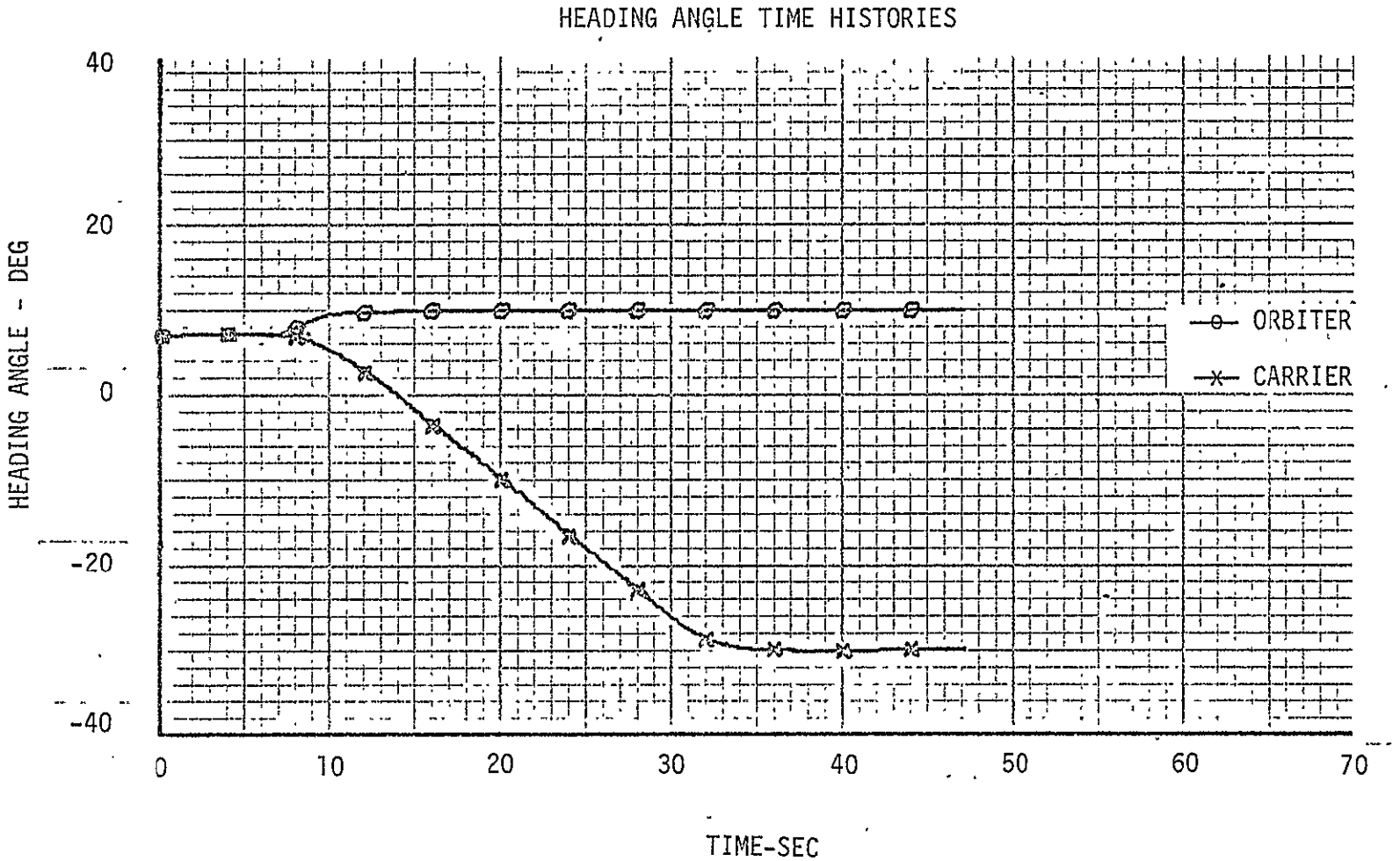

FIGURE 45
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

LOCAL HORIZONTAL PITCH ATTITUDE TIME HISTORIES

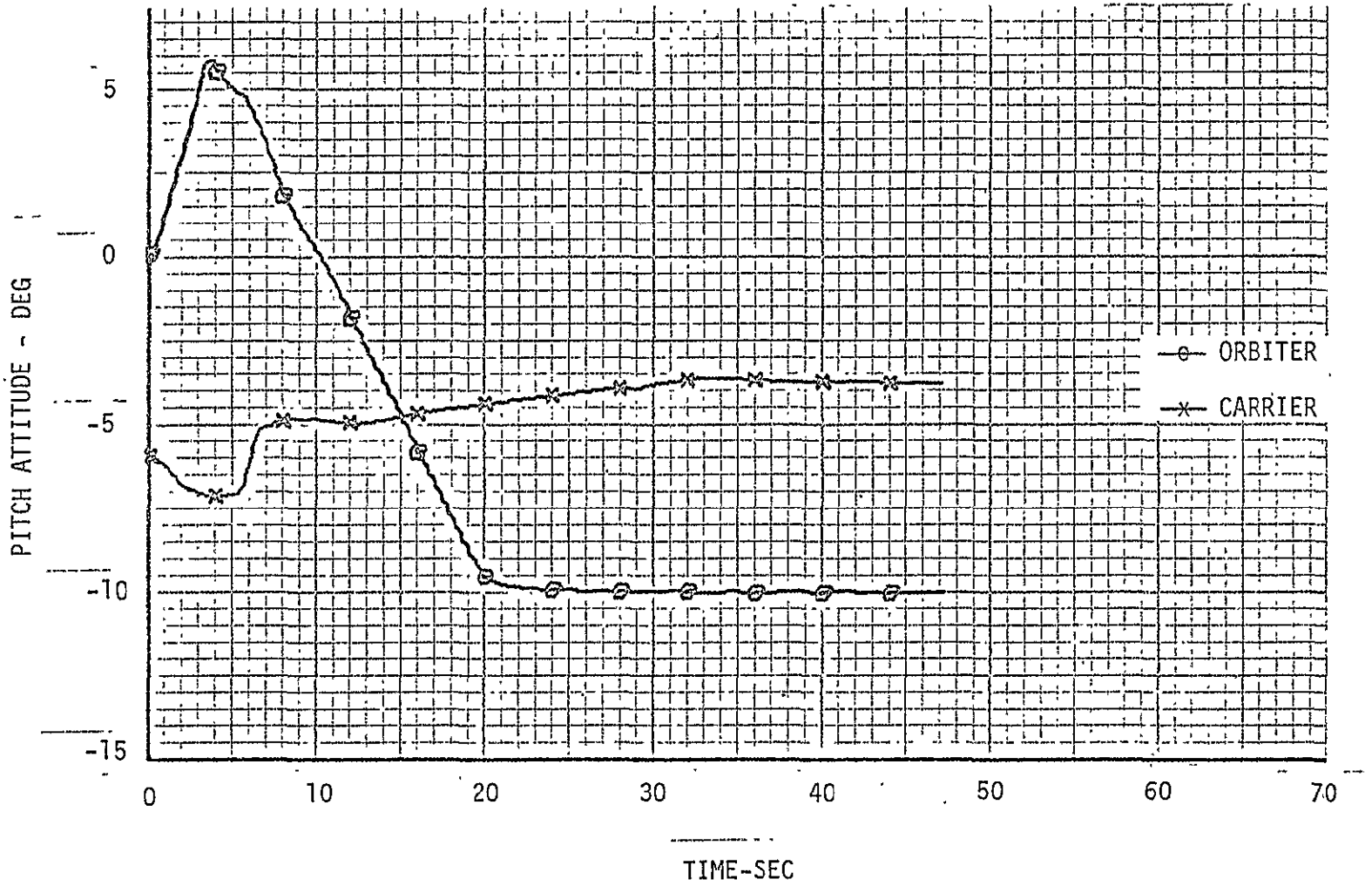

FIGURE 46
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

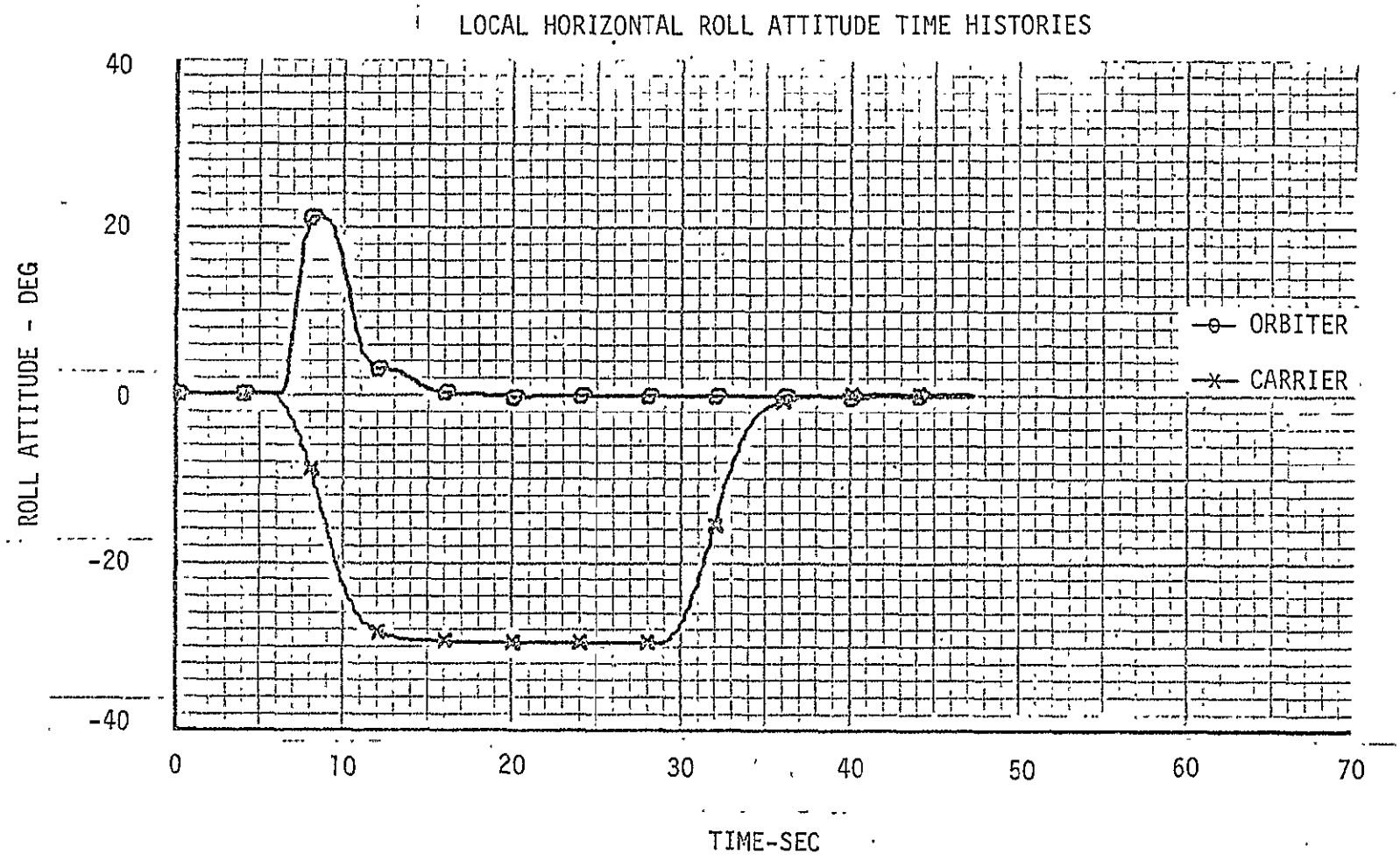

FIGURE 47
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

PITCH RATE TIME HISTORIES

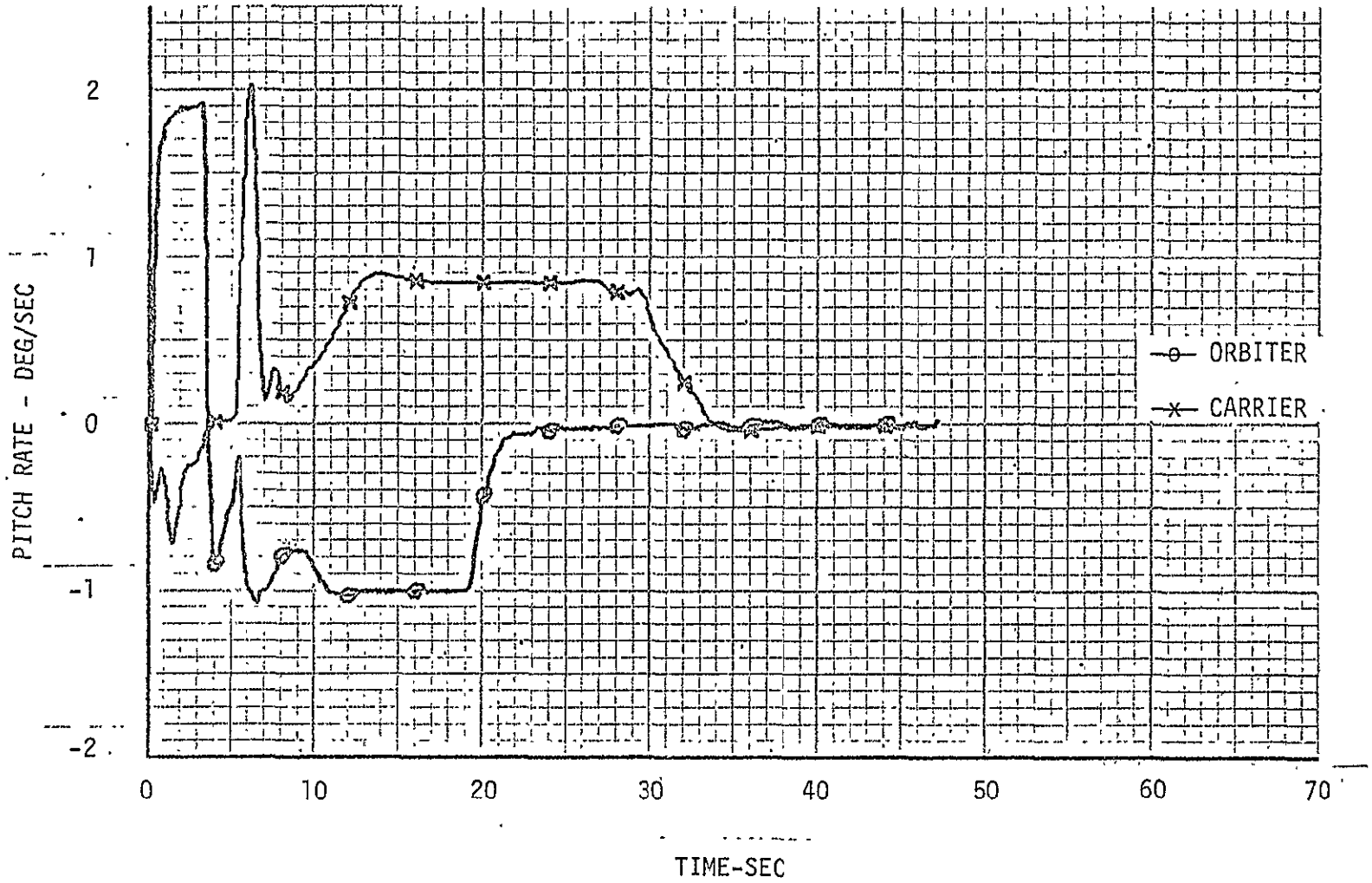

FIGURE 48
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

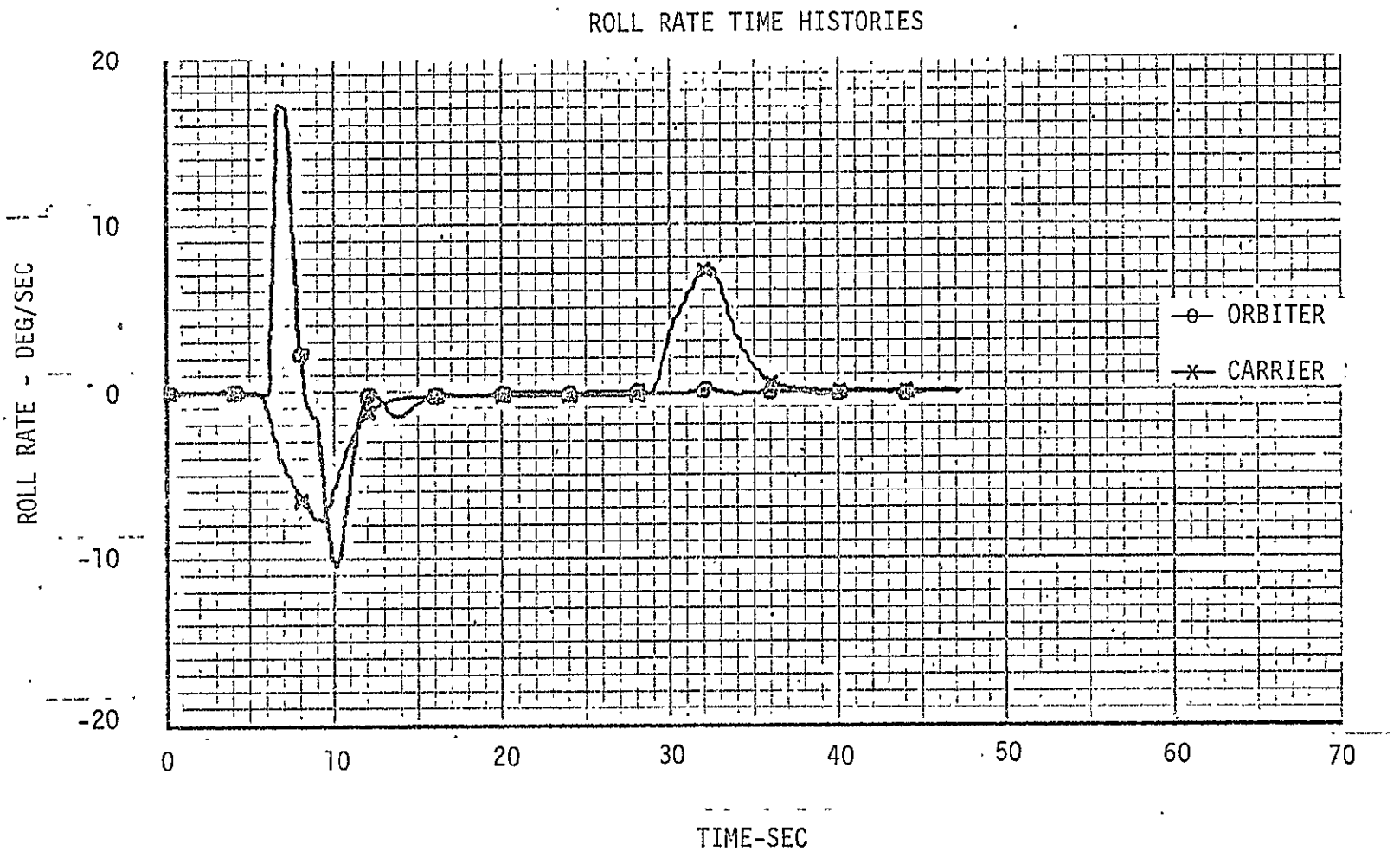

FIGURE 49
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

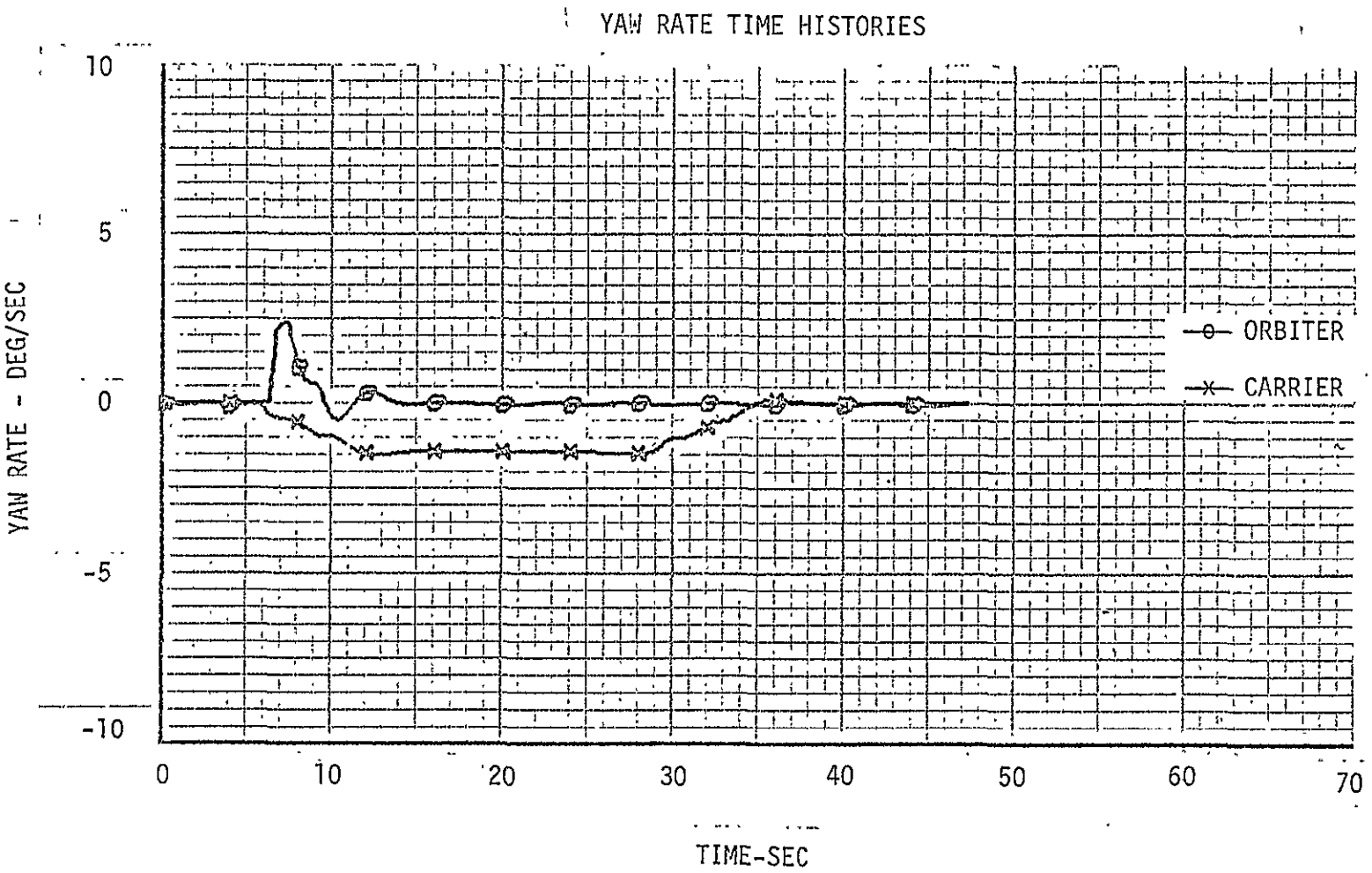

FIGURE 50
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

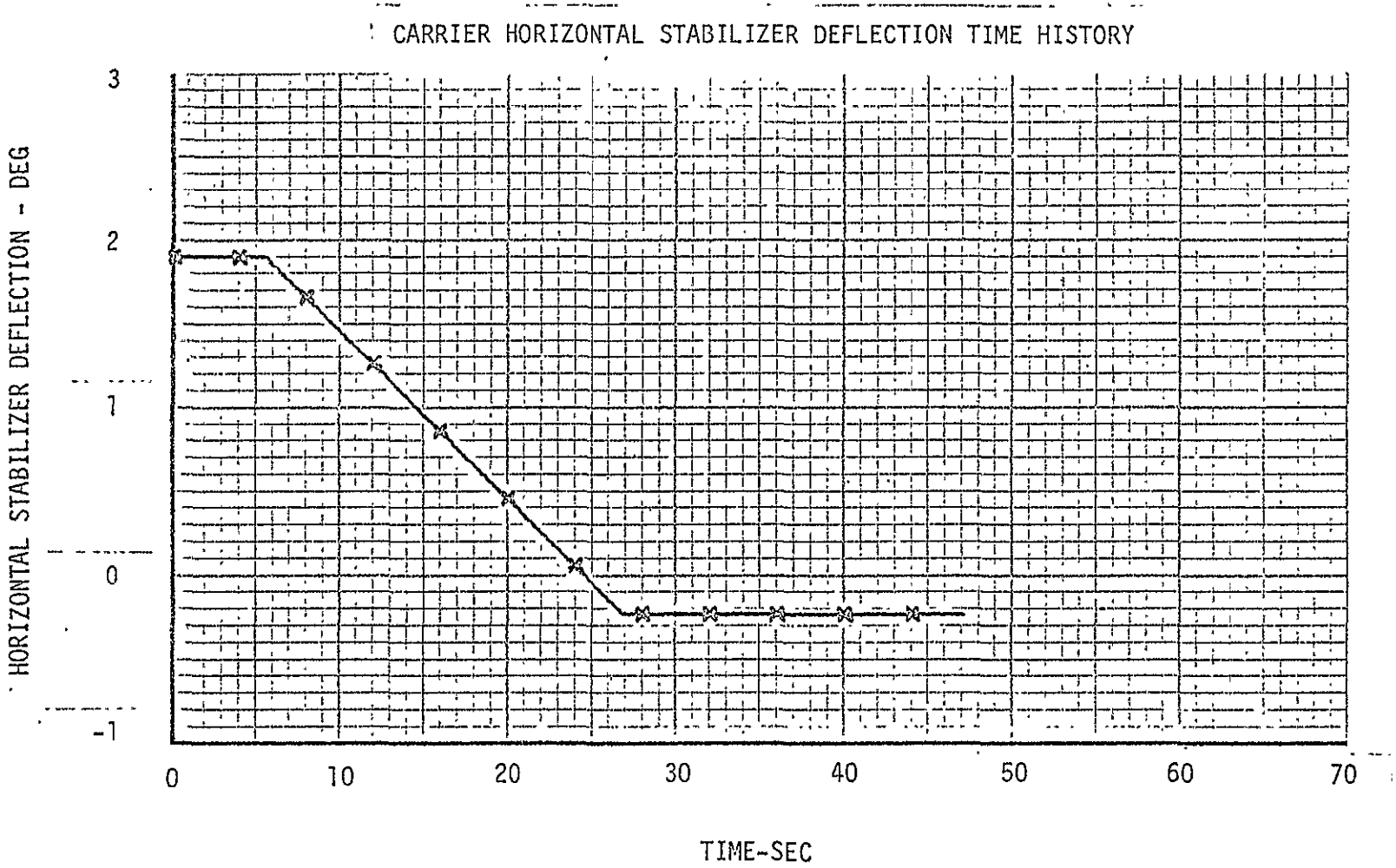

FIGURE 51
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

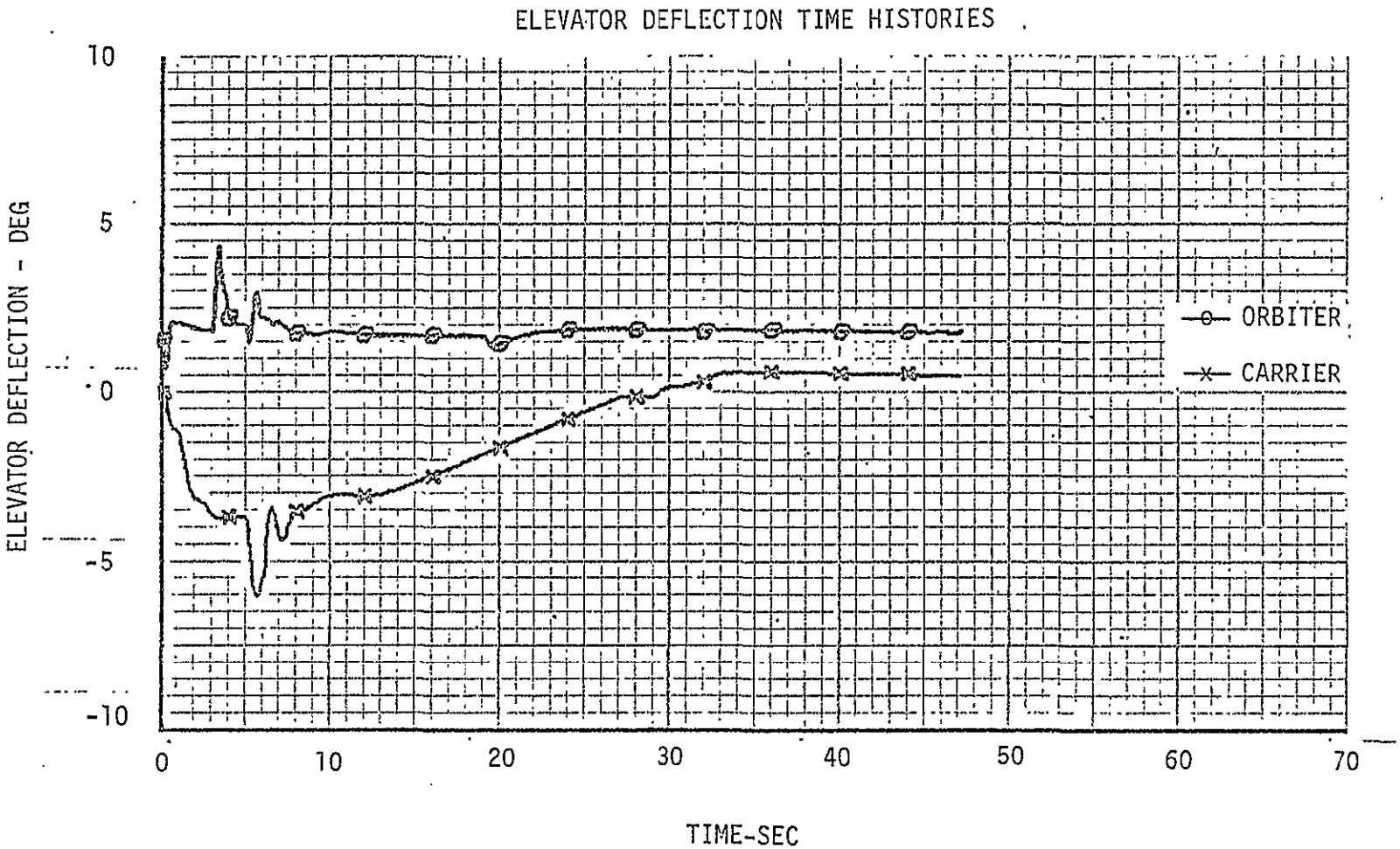

FIGURE 52
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

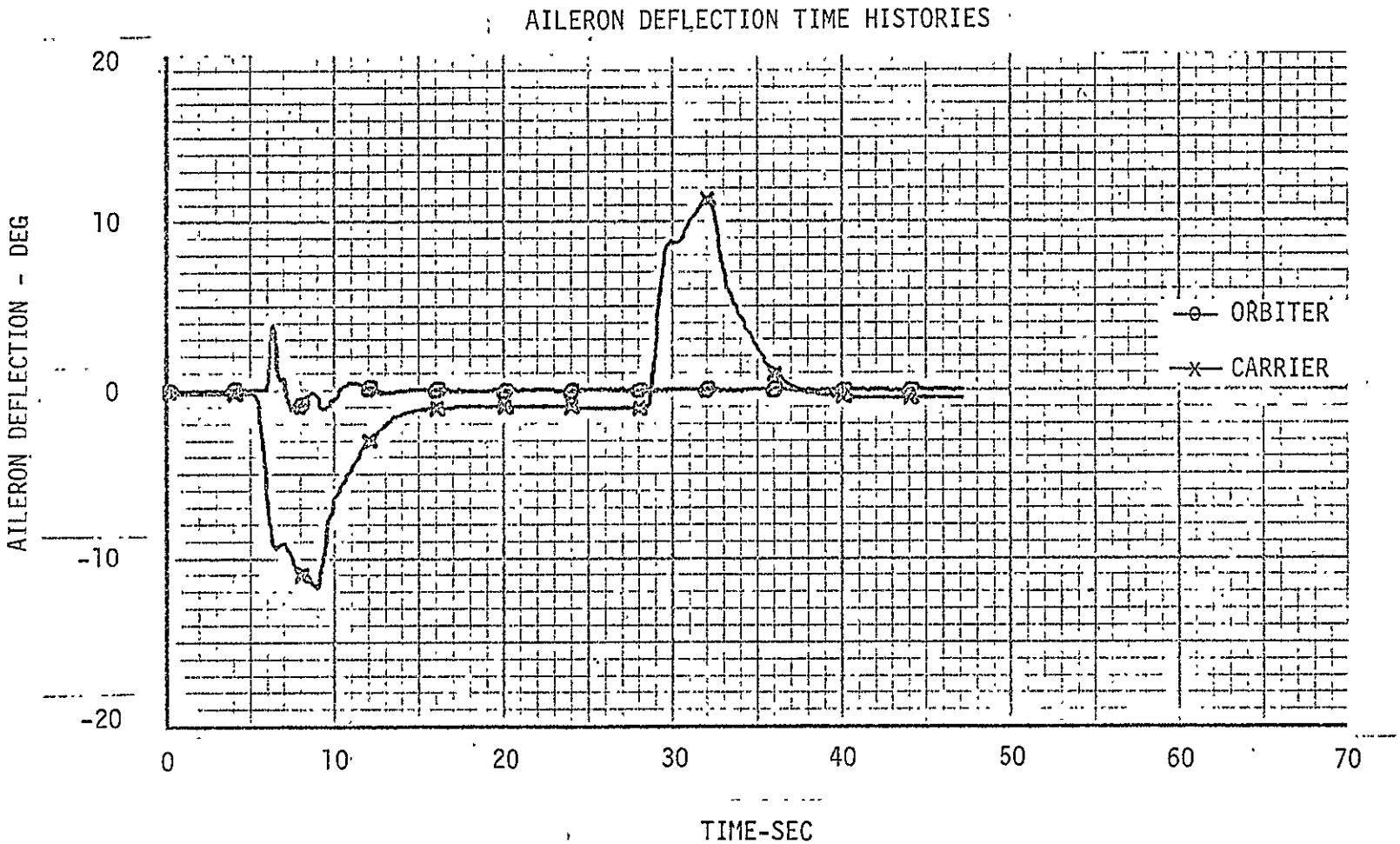

FIGURE 53
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

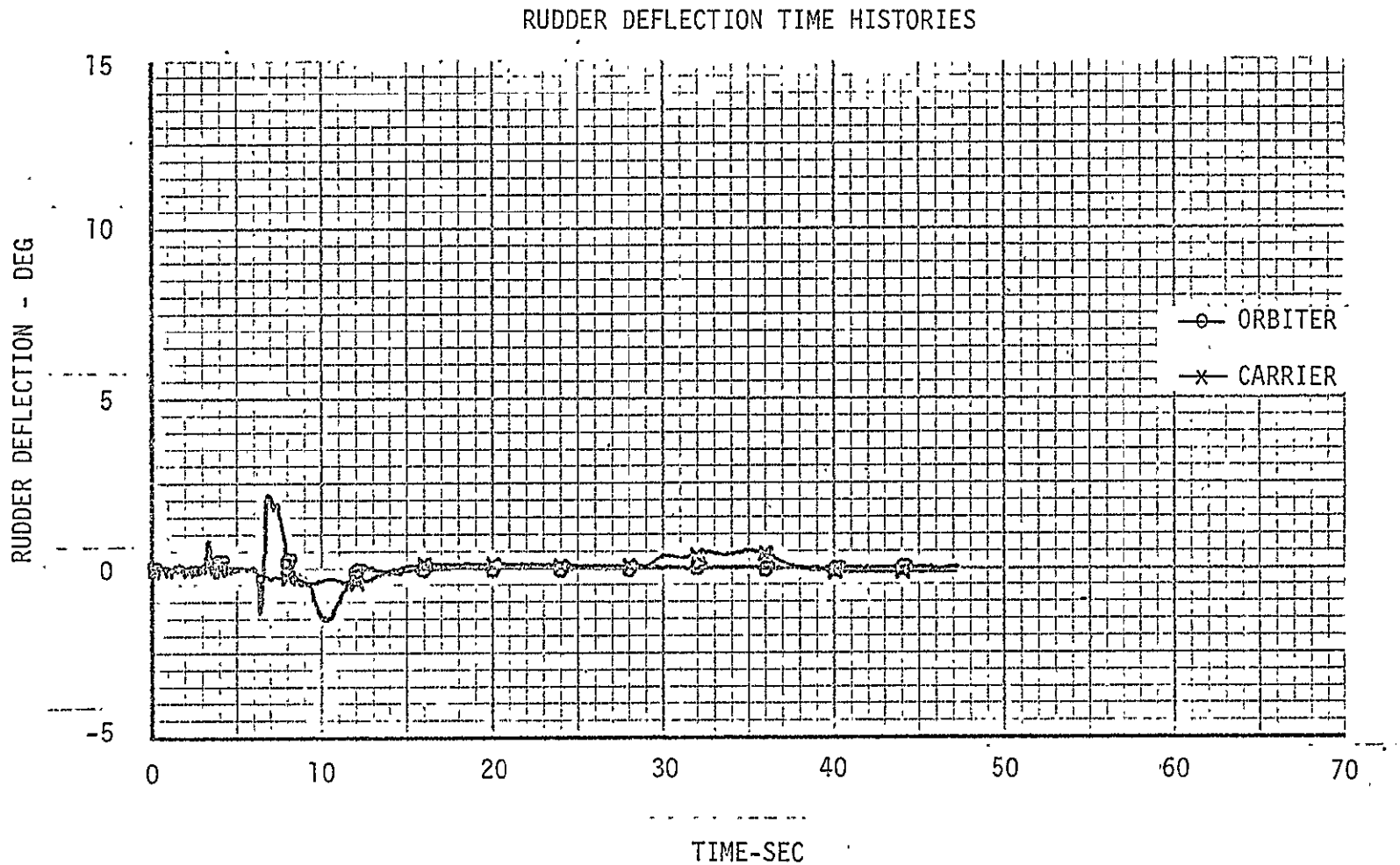

FIGURE 54
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

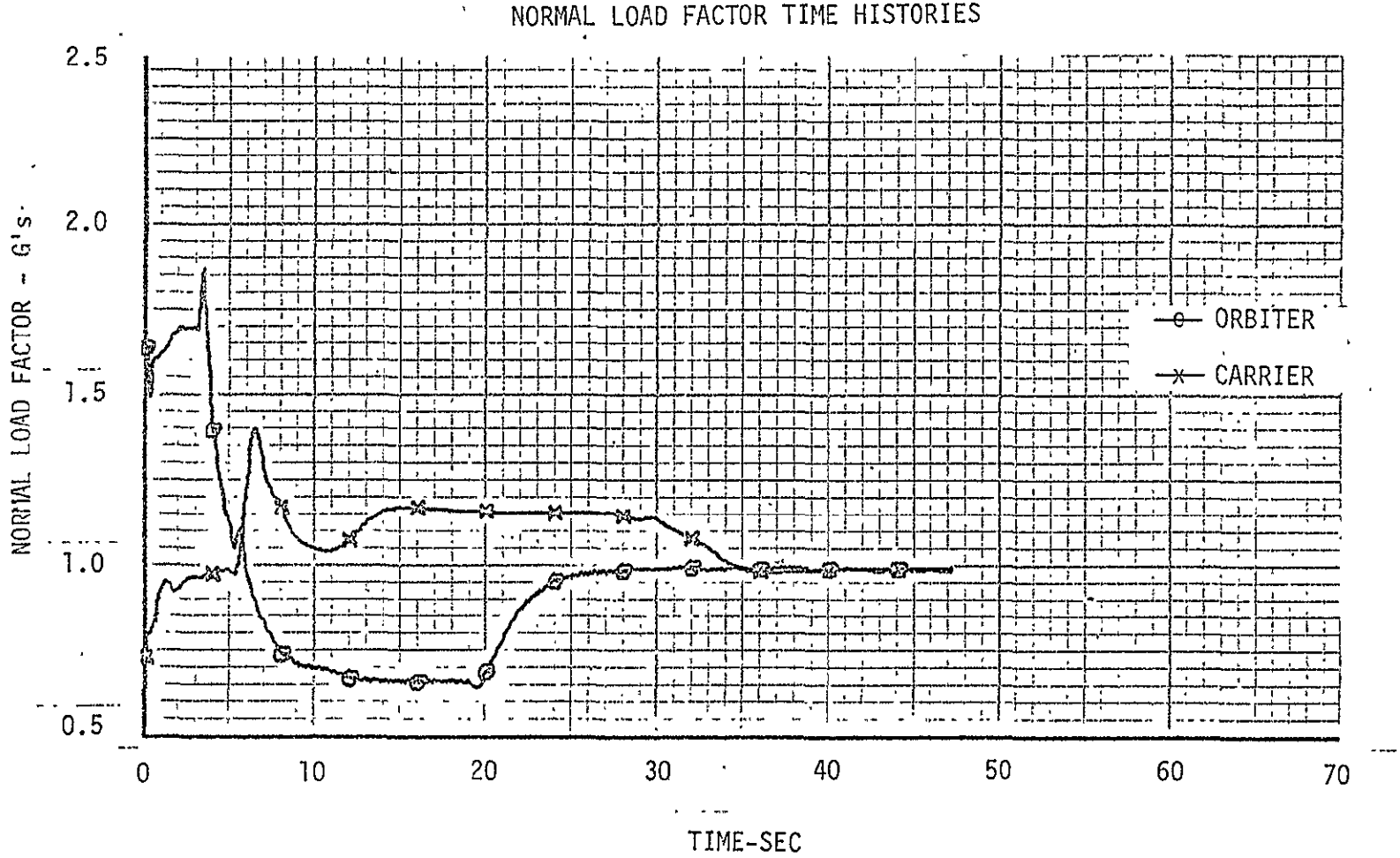

FIGURE 55
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

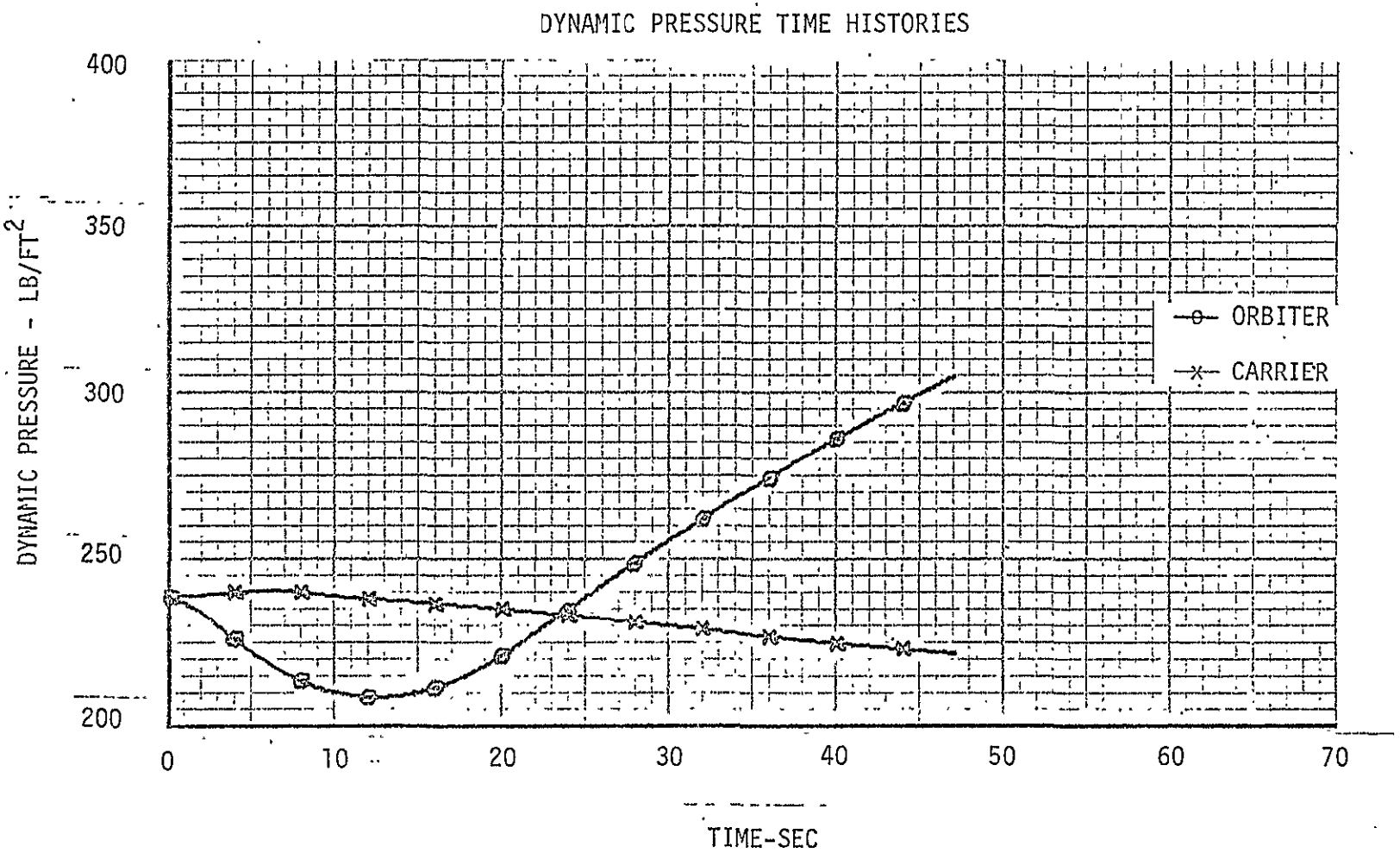

FIGURE 56
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

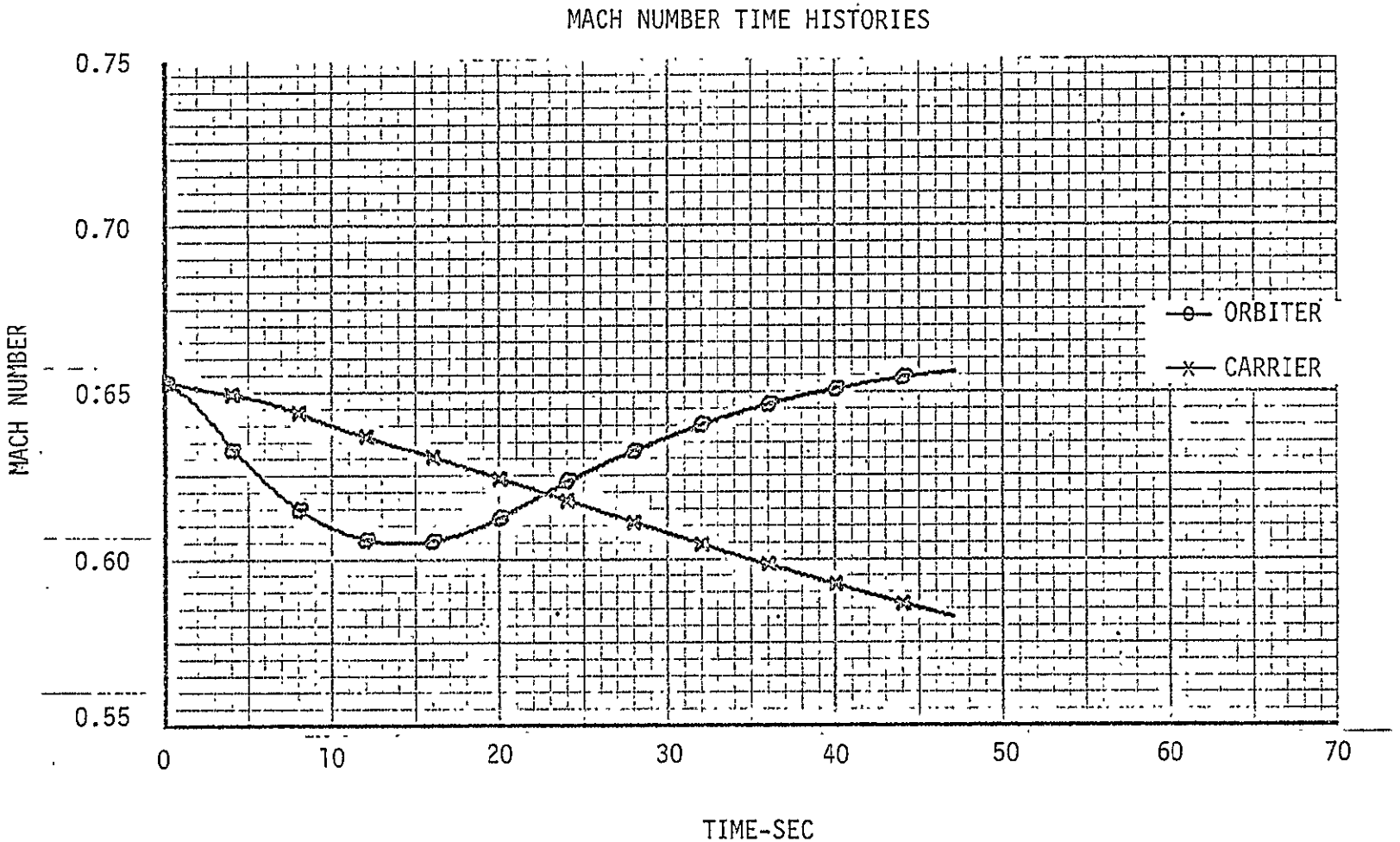

FIGURE 57
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

EARTH RELATIVE AIRSPEED TIME HISTORIES

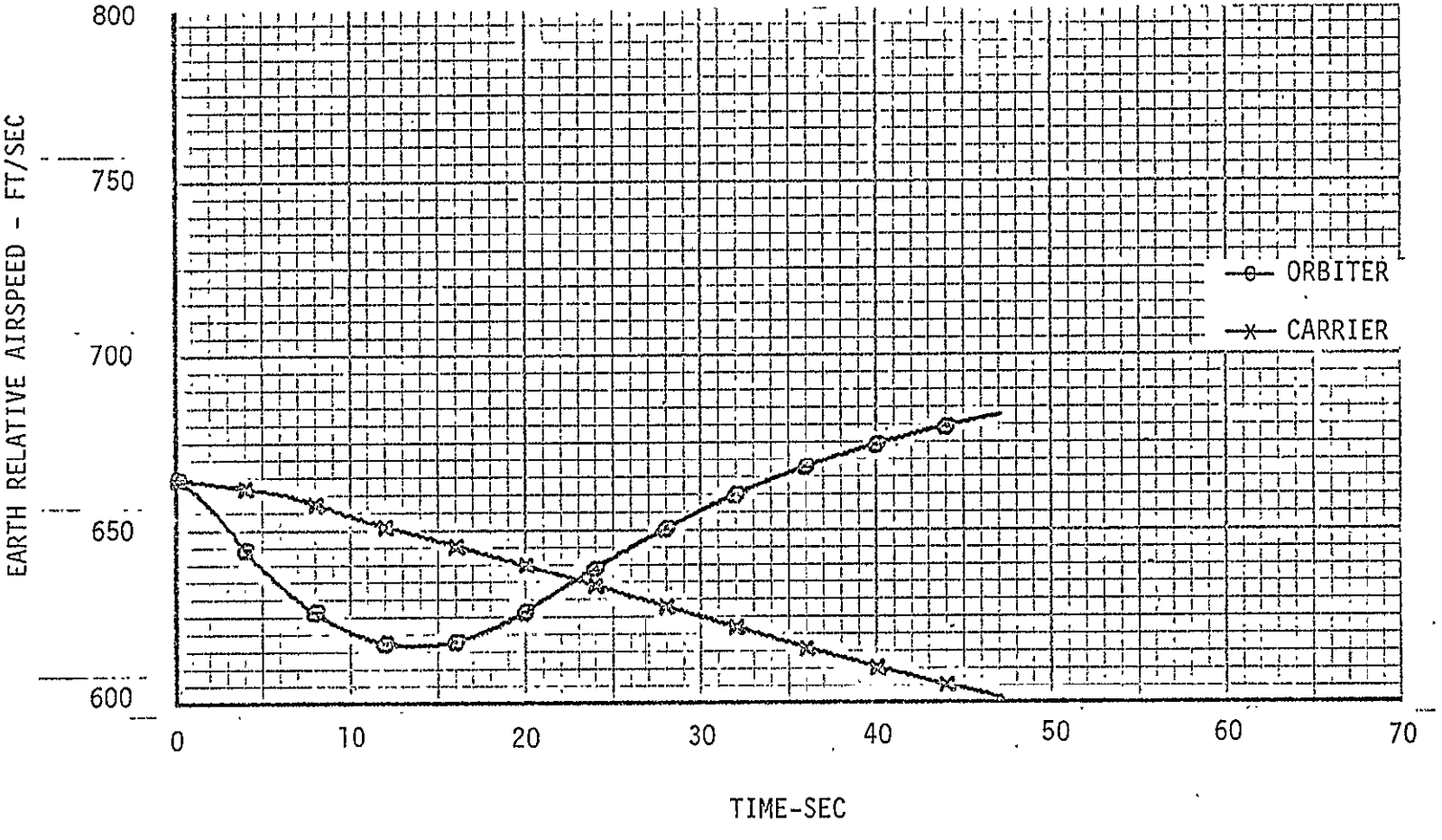

FIGURE 58
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

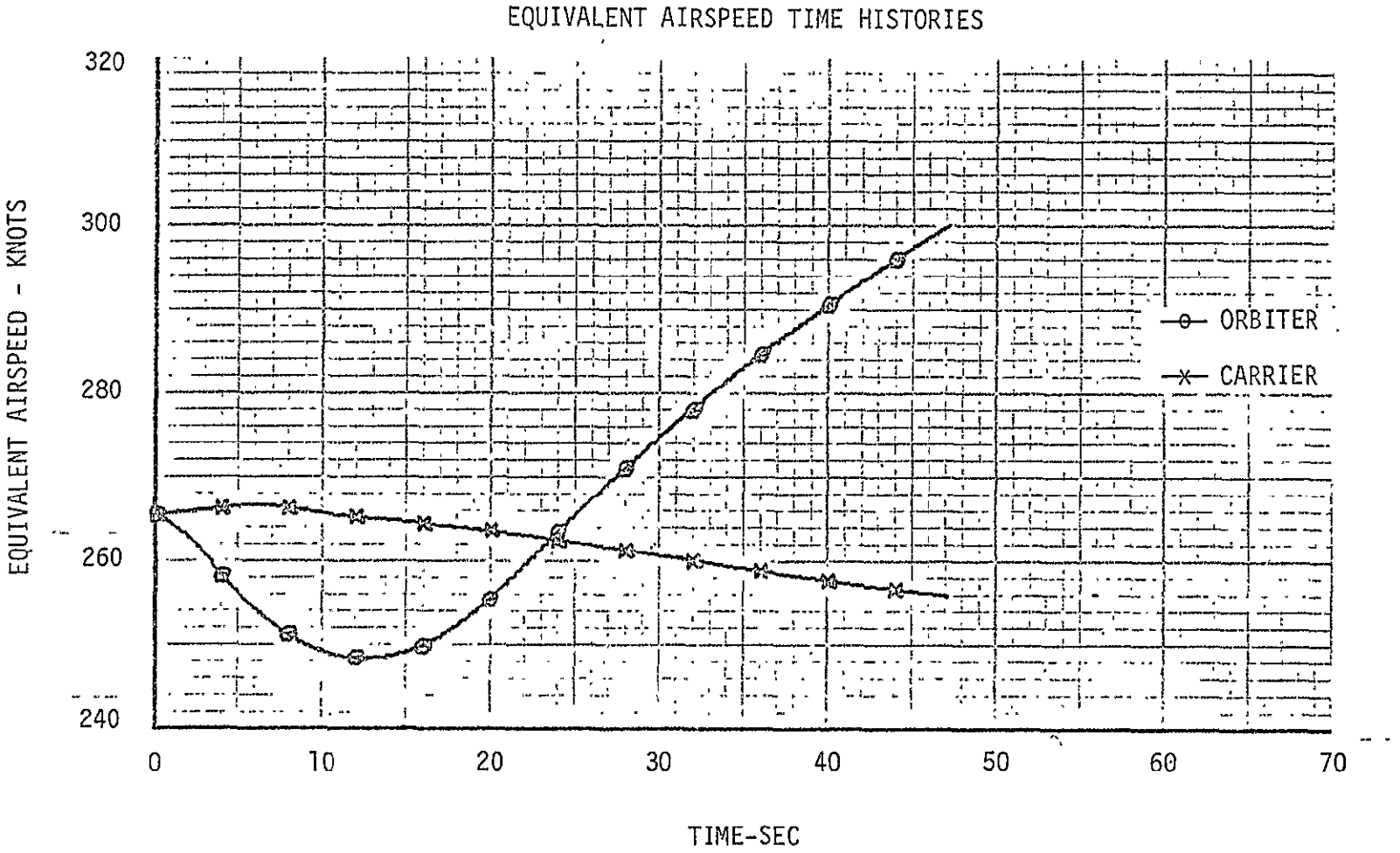

FIGURE 59
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B, 150000 LB ORBITER

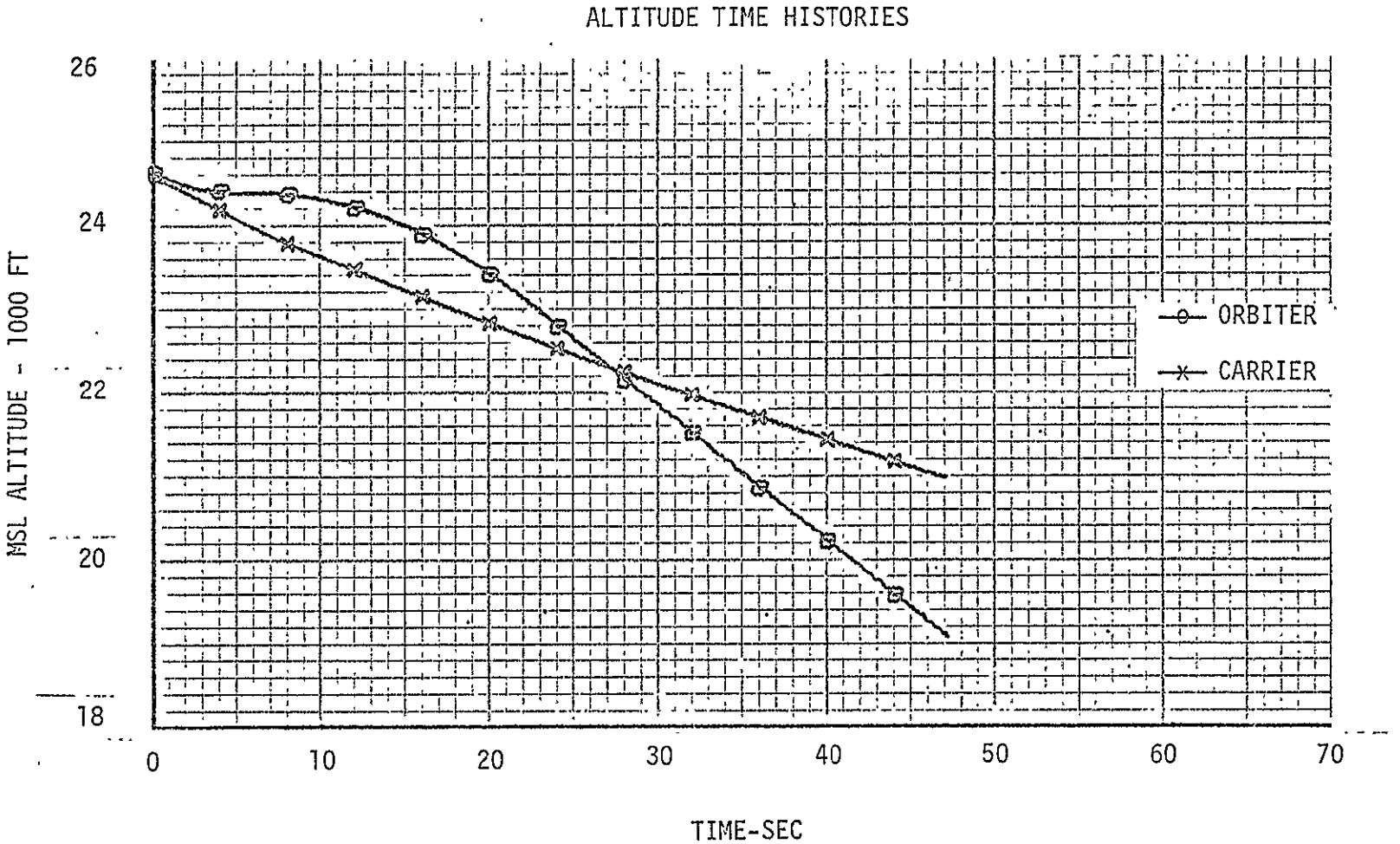

FIGURE 60
ALT SEPARATION REFERENCE TRAJECTORY
TAILCONE ON, CG @ 65.9% L_B; 150000 LB ORBITER